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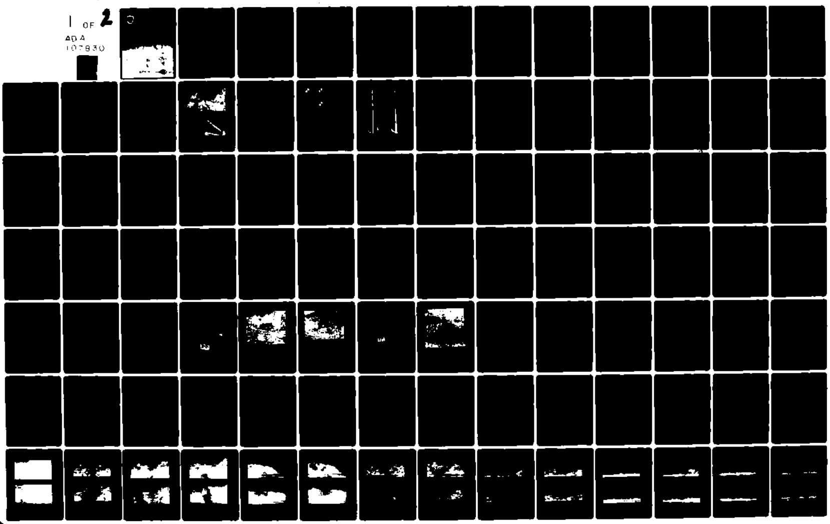

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METHODOLOGY INVESTIGATION

FINAL REPORT

ENVIRONMENTAL REALISM--BATTLEFIELD OBSCURATION IN THE TROPICS

by

CPT Marie T. Martinucci
Robert J. Fuchs

January 1981

Approved for public release, distribution unlimited.

UNITED STATES ARMY TROPIC TEST CENTER

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A joint methodology investigation between US Army Waterways Experiment Station (USAWES) and US Army Tropic Test Center (USATTC) was conducted in the humid tropics of the Republic of Panama from July through October 1980. The objective was to determine the relationship between soil parameters and obscuration features of clouds produced by munitions and explosives in the humid tropics. A combined total of sixty-six 15-pound TNT charges and 105- and 155-millimeter ammunition rounds were detonated in various types of vegetation at three sites, including an ocean beach site. It was concluded that obscuration from

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munitions and explosives is minimal in the humid tropics during the wet season. Correlations between soil parameters and obscuration parameters were weak; however, vegetation levels did have an effect on cloud size.

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FOREWORD

This cooperative research project was conducted in the Republic of Panama by the US Army Tropic Test Center (USATTC) and the US Army Waterways Experiment Station (USAWES). It was completed under the guidance of CPT Marie T. Martinucci, Test Officer, Mr. Robert J. Fuchs, Mathematical Statistician, USATTC; and Mr. James Mason, Project Coordinator, USAWES. Mr. Robert H. Johnson, Engineering Technician, USATTC, was responsible for survey and soil measurements in the field, as well as for laboratory analysis of soil data.

SECTION 1. SUMMARY

1.1 BACKGROUND

a. The performance of many modern weapons systems can be affected adversely by heavy concentrations of dust and smoke in the air. In recent years, a systematic effort has been underway to assess such effects, both in the field and through mathematical computer models, to meet the need for a more realistic battlefield representation. Basic computer models describing physical phenomena, such as scattering and absorption of radiation, have been applied to battlefield scenarios characterizing a wide range of conditions. The results have been used to produce parametric computer models for obscured conditions similar to certain geographic or climatic regions. In most cases, engineering computer models, developed to describe the performance of a number of weapons systems, have, or will have, incorporated such parametric models. While these models serve the needs of the engineering community in developing and, to some extent, evaluating such weapons systems, a further step is desired. That step is to use models to determine the effective deployment of weapons systems.

b. A fundamental gap must be bridged—the link between obscurant material and terrain. Much of the obscurant material on the battlefield originates in the soil and is raised by battle activity. Before this link can be understood properly, the relationship between specific combat activities and obscurant production must be described accurately. This was the immediate task of the USAWES/USATTC cooperative project.

1.2 OBJECTIVE

Determine the relationship between soil parameters and obscuration features of clouds produced by munitions and explosives in the humid tropics.

1.3 SUMMARY OF PROCEDURES

a. The test was conducted at Empire Range 6 (on the Pacific side of the Isthmus of Panama), and at Mindi Farm and Pina Beach (on the Atlantic side). In-place detonations of 155-millimeter rounds, 105-millimeter rounds, and 15-pound (6.8 kg) blocks of TNT were employed at Range 6 and Mindi Farm, while only TNT was used at Pina Beach.

b. At Empire Range 6, three blast areas were used. Two of these areas were chosen because each area was covered by a different grass species: *Gynerium sagittatum* (3 to 4 meters high) and *Panicum* sp (1 meter high). The third area was under the jungle canopy. Half of the blast surface on each of the two grass areas was covered for several days to promote drying of the soil. The covering was high enough above the ground to allow soil moisture to evaporate without destroying the vegetation. It was not removed until immediately before blasting to minimize exposure to rain. No attempt was made to dry the soil in the third (jungle canopy) area of Range 6.

(1) Three shots (one each of 155mm, 105mm, and TNT) were detonated statically in three different grass levels: uncut grass; grass cut to 0.3 to 0.5 meter; and bare soil cleared of all grass. The grass was not cut in the area under the jungle canopy.

(2) The 155- and 105-millimeter munitions were set, nose down, on the surface of the soil at a 30-degree angle of attack, and detonated electrically. The TNT was placed so that the total charge detonated simultaneously.

c. At the Pina Beach site, eight TNT charges were detonated. The charges were set on the ground surface in six different areas: white, saturated sand (shoreline); white, wet (top centimeter partially dry) sand; black, wet (top centimeter partially dry) sand; Ipomoea pes-caprae (morning-glory); Hymenocallis americana (spider lily); and Panicum maximum (2 to 3 meters high). No munitions were detonated at the Pina Beach site and no artificial drying of the soil was attempted.

d. At Mindi Farm, the munitions and charges were detonated in three different levels of vegetation: Gynerium sagittatum (3 to 4 meters high), Gynerium sagittatum cut to 0.3 to 0.5 meter, and bare soil cleared of all vegetation. The explosives were set and detonated on the soil surface in the same manner as at Range 6.

e. At all sites, bulk soil samples were taken before and after the detonations took place. Cone index (CI) measurements were made and moisture and density samples were collected. Crater measurements were made of symmetric and asymmetric craters. Crater profiles and photographs are presented in Appendix C. Blow-out material was collected at points 3, 6, and 9 meters from the center of the blast on the four points of the compass. (Jungle density precluded collection of blow-out material for the low canopy area of Range 6.) Laboratory analysis was performed on the bulk samples and the blow-out material.

f. Still photograph and video tape records were made of all detonations at all sites. Analysis of video tapes provided data on cloud obscuration in a vertical plane. Representative cloud photographs are provided in part 4 of Appendix C.

1.4 SUMMARY OF RESULTS

a. TNT charges produced the largest areas of obscuration for the longest period of time, followed by 155- and 105-millimeter rounds. The obscuration from TNT resulted mainly from the black, TNT-produced smoke, rather than from dirt or dust. Because of this, the cloud sizes at Pina Beach (TNT only) were comparable to those produced from TNT at inland tropic sites.

b. Vegetation levels affected cloud sizes to some degree. Munitions in high, uncut grass produced smaller clouds than munitions in cut grass or bare soil. The high grass probably had a damping effect on the production of dust and other suspended particles in the air.

c. Crater sizes were largest at the Mindi Farm site where the soil was wettest. Resulting obscured areas were largest for the first 10 seconds following detonation, but fell off rapidly, leaving no obscuration by 20 seconds.

d. In general, correlations between obscuration parameters and soil parameters were weak.

1.5 ANALYSIS

No consistent correlations between obscuration parameters and soil parameters were noted in this study. Combinations of prediction variables (e.g., cone indexes, surface moisture, and Atterburg Limits) did fit a multiple regression model in adequately predicting cloud size. However, lack of consistency shows that the relationships are not strong enough to model without further data.

1.6 CONCLUSIONS

Tropic wet season soils do not contribute greatly to obscuration. Nearly all obscuration was caused by the smoke from the munitions or explosive, and dissipated within 20 to 40 seconds. Tropic vegetation does influence the size of clouds produced—munitions produced smaller clouds in tall grass than in short grass or bare soil.

1.7 RECOMMENDATIONS

a. Perform follow-up study in Panama during the dry season to document effects of tropic soils on obscuration produced by munitions and explosives. These data then can be compared with data collected during the wet season.

b. Sample airborne particles within the clouds during the tropic dry season to determine proportions of dust, smoke, and debris.

SECTION 2. DETAILS OF INVESTIGATION

2.1 MATERIALS AND METHODS

2.1.1 Surface and Soil Types. For this study, test shots were detonated during the wet season (July and August) at three sites--Empire Range 6, Mindi Farm, and Pina Beach (figure 1). A site description for each crater is presented in table B-1. These three sites differed in surface and soil types, as described below.

a. Surface Types.

(1) *Gynerium sagittatum* (Range 6 and Mindi Farm): Grass 3 to 4 meters high, 60 to 70 stems-per-square-meter density, with stem size ranging from 3 to 13 millimeters in diameter. Root depth was approximately 30 centimeters, and distance between grass clumps averaged 30 to 60 centimeters.

(2) Cut *Gynerium sagittatum* (Range 6 and Mindi Farm): Description in subparagraph 2.1.1a(1), above, applies, except that grass was cut to 0.3 to 0.5 meter.

(3) Bare, cleared soil (Range 6 and Mindi Farm): To produce this type of surface, a bulldozer was used to clear all grass and scrape down to the bare soil. An engineering technician supervised the operation to insure that only a minimal amount of top soil was removed.

(4) *Panicum* sp (Range 6): Grass 1 to 2 meters high, 90 to 100 stems-per-square-meter density, with stem size ranging from 1.6 to 6 millimeters in diameter. Root depth was approximately 15 centimeters, and distance between grass clumps averaged 46 to 77 centimeters.

(5) Cut *Panicum* (Range 6): Description in subparagraph 2.1.1a(4), above, applies, except that grass was cut to 0.3 meter.

(6) Low jungle canopy (Range 6): Trees 11 to 14 meters tall, with stems spaced approximately 1.8 meters apart, and stem size ranging from 2 to 20 centimeters in diameter.

(7) White, saturated sand (Pina Beach): Located on the shoreline.

(8) White, wet sand (Pina Beach): Located on the beach; top centimeter partially dried by sun and wind.

(9) Black, wet sand (Pina Beach): Located on the beach; top centimeter partially dried by sun and wind.

(10) *Ipomoea pes-caprae* (Pina Beach): Small, leafy, ground vines (morning glories), with approximately 30-percent ground cover.

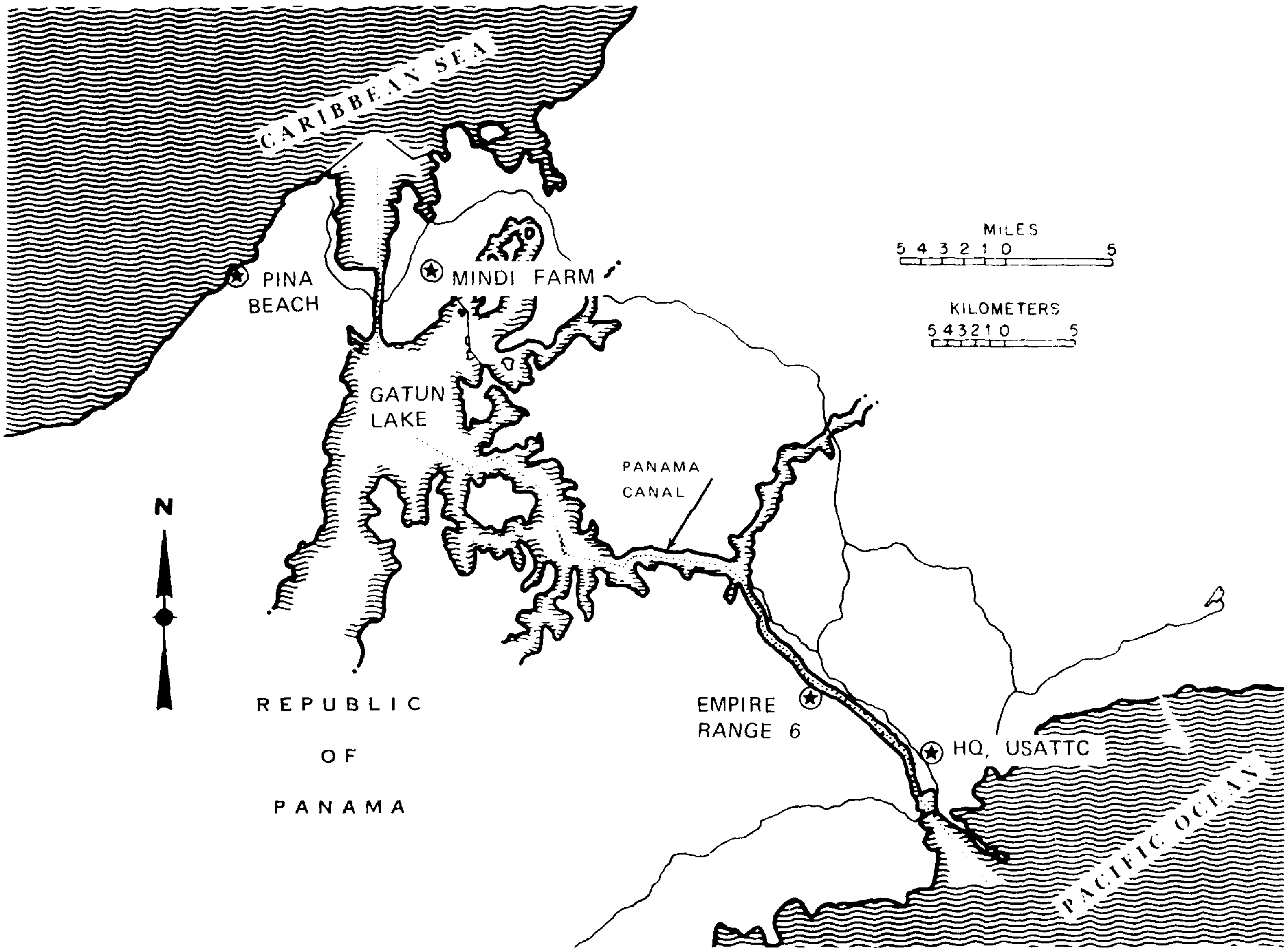


Figure 1. Locations of the Three Test Sites--Empire Range 6, Mindi Farm, and Pina Beach.

(11) Panicum maximum (Pina Beach): Grass 2 to 3 meters tall, 70 to 80 stems-per-square-meter density, with stem size ranging from 3 to 9 millimeters in diameter. Root depth was approximately 20 centimeters, and distance between grass clumps averaged 0.3 to 0.5 meter.

(12) Hymenocallis americana (Pina Beach): Herb 0.75 to 1 meter tall with white flowers at top (spider lily). (Provided approximately 80-percent ground cover.) Root depth was approximately 15 centimeters, and stem diameters ranged from 13 to 40 millimeters.

b. Soil Types (soil was too firm to perform remolding tests).

(1) Empire Range 6: Relatively undisturbed lateritic, silty clay soil. From the available evidence and technology, it cannot be determined if Range 6 is undisturbed land or fill from the Panama Canal. However, the soil has been in place for at least 60 years. CI readings (subparagraph 2.1.5b(1)(c)) indicate that the probable fill area has been compacted (primarily by rainfall) to CI values similar in magnitude to the perimeter area. Homogeneous soil with rocks, ranging in size from small gravel to 2 feet (0.6 m) in diameter, is found in both locations and has relatively high CI readings. In some cases, CI readings were erratic because the cone penetrometer struck and slipped off rocks. Although the probable fill area has a rock density approximately twice that of the perimeter area, both areas have an equivalent soil strength. Results of a combined mechanical analysis of four soil samples from Range 6 are presented in figure 2.

(2) Mindi Farm: Primarily silt with some fine sand and traces of clay. The site was situated on top of a hill in rolling terrain. The ground surface was relatively smooth, and the high position and slope promoted rapid drainage. Results of a combined mechanical analysis of four soil samples from Mindi Farm are presented in figure 3.

(3) Pina Beach: Fine coastal sand with traces of silt and gravel. The site was situated on a sandy beach on the Atlantic side of the Isthmus, approximately 1 kilometer southwest of the mouth of the Chagres River. Results of a combined mechanical analysis of two soil samples from Pina Beach are presented in figure 4.

2.1.2 Blast Site Coverings

As mentioned in subparagraph 1.3b, half of the blast sites at Range 6 were covered and drainage was provided to allow the surface soil to dry. Four weeks before detonation, plastic tents were positioned 3 feet (0.9 m) to 6 feet (1.8 m) above the detonation area, and secured to the ground with tent pegs (figure 5). In tall grass blast areas, the tents were laid directly over the grass and secured to the ground. All tents were inspected weekly and repaired as required.

2.1.3 Munitions and Charges

155-millimeter, HE, M107, rounds; 105-millimeter, HE, M1, rounds; and 15-pound (6.8 kg) blocks of TNT were detonated. The 155- and 105-millimeter

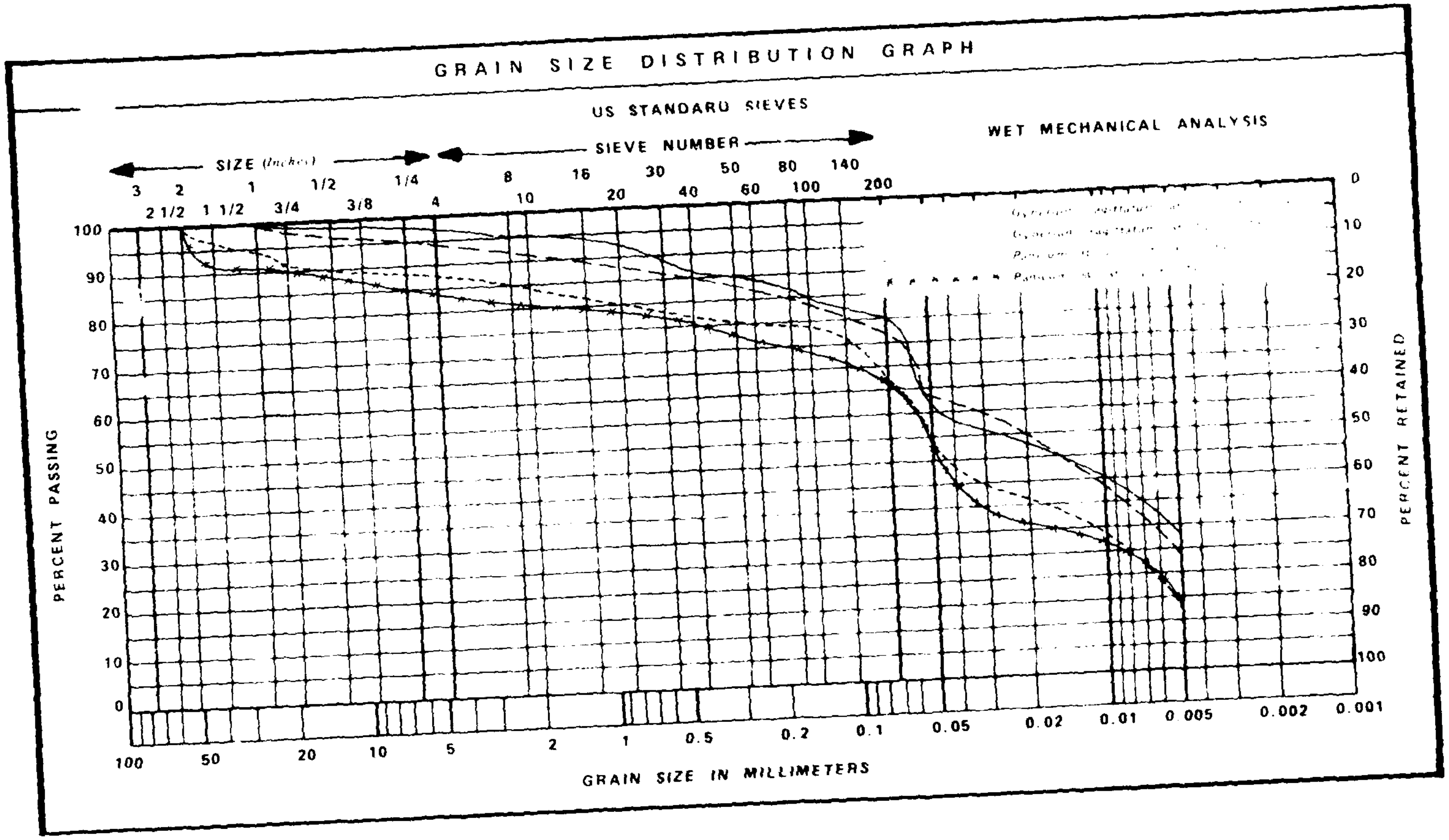


Figure 2. Combined Mechanical Analysis Results--Empire Range 6.

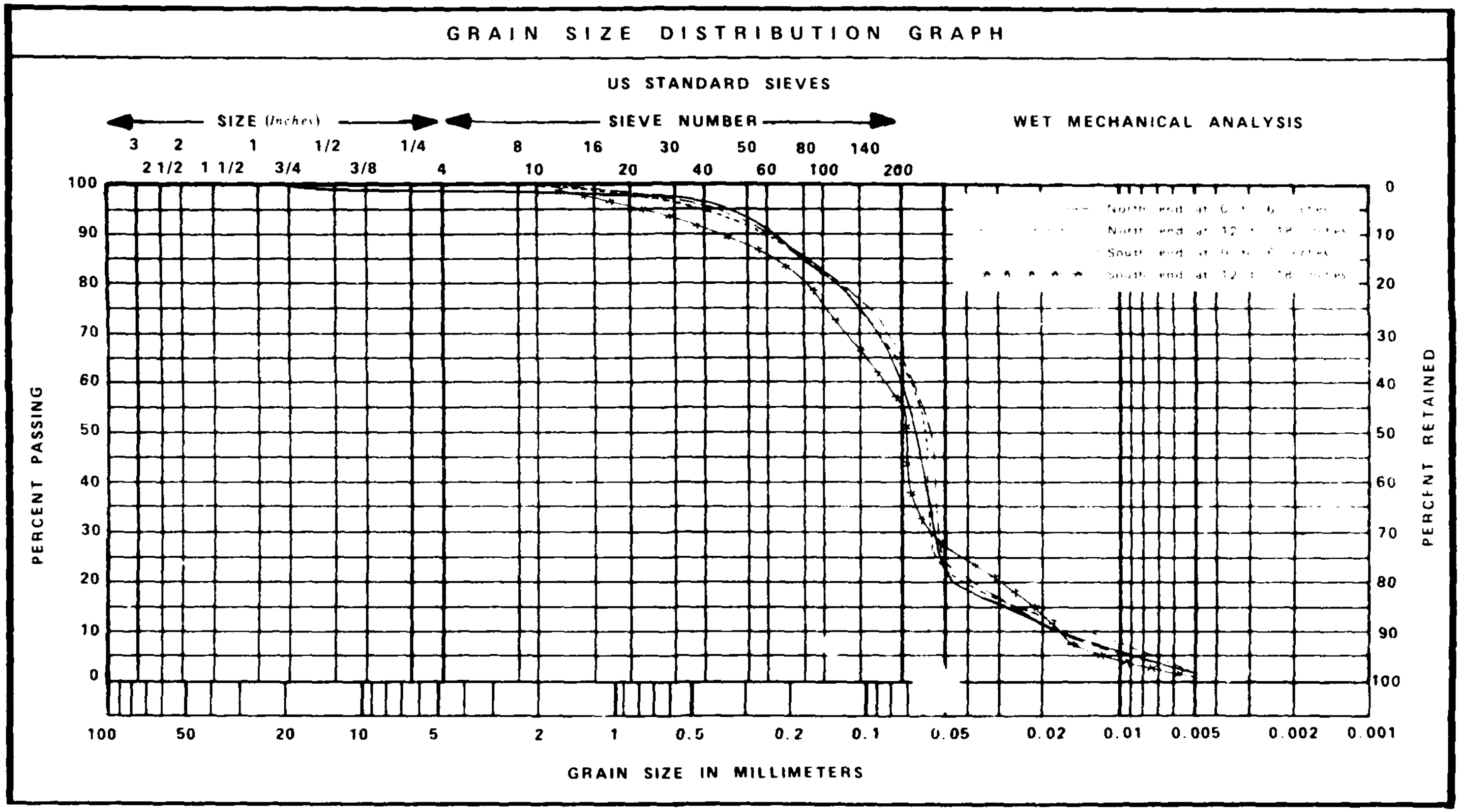


Figure 3. Combined Mechancial Analysis Re..ults--Mindi Farm.

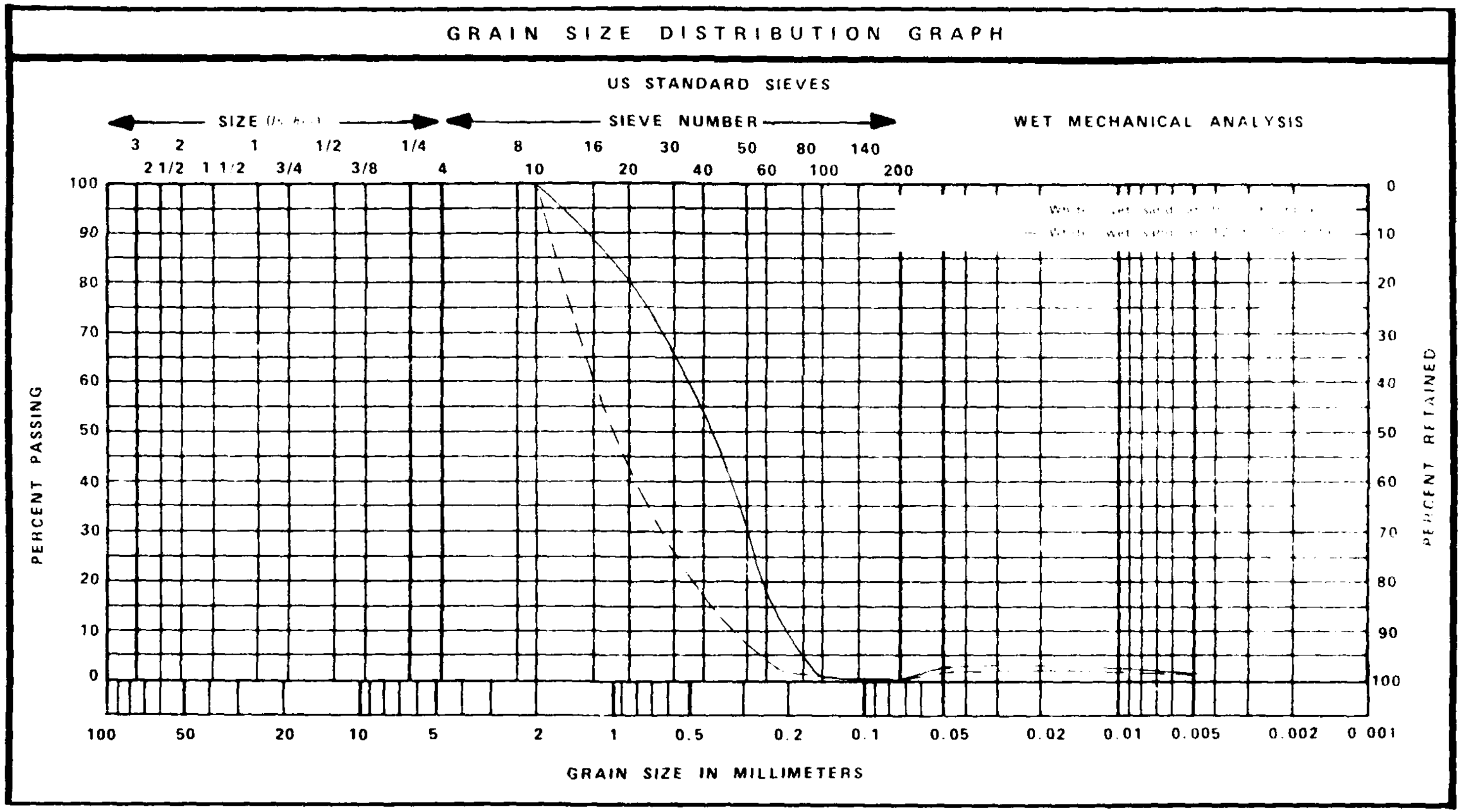


Figure 4. Combined Mechanical Analysis Results--Pina Beach.

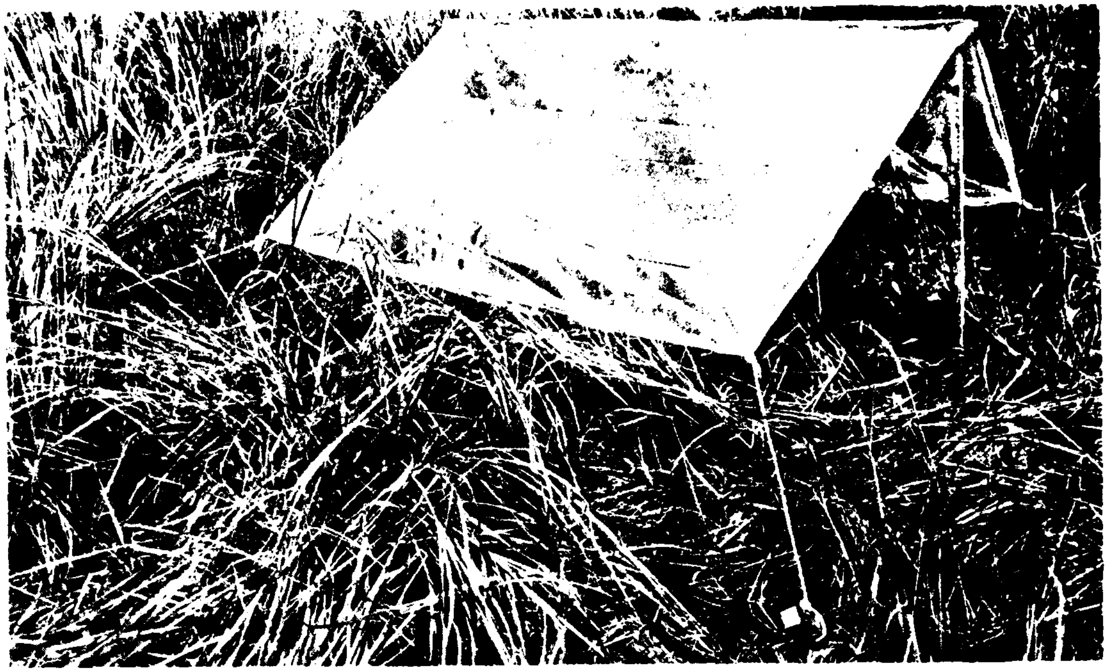


Figure 5. Plastic Tent Used to Cover Blast Area.

rounds were placed on wooden stands angled at 30 degrees from the ground (figure 6). (This allowed the round to be placed at an angle of ground entry similar to a round fired by a field artillery unit.) TNT charges were placed directly on the ground for all detonations. All explosives were dual-primed with electric blasting caps as the primary system, and a back-up 10-minute time fuze. For 20 shots (six 155mm and five 105mm rounds, and nine TNT charges), the M122 firing device was used in lieu of electrical detonation. The M122 receiver was placed in a 6-inch (15.2 cm) hole, 2 to 3 meters from ground zero. The M122 transmitter was activated at the site observation point (OP).

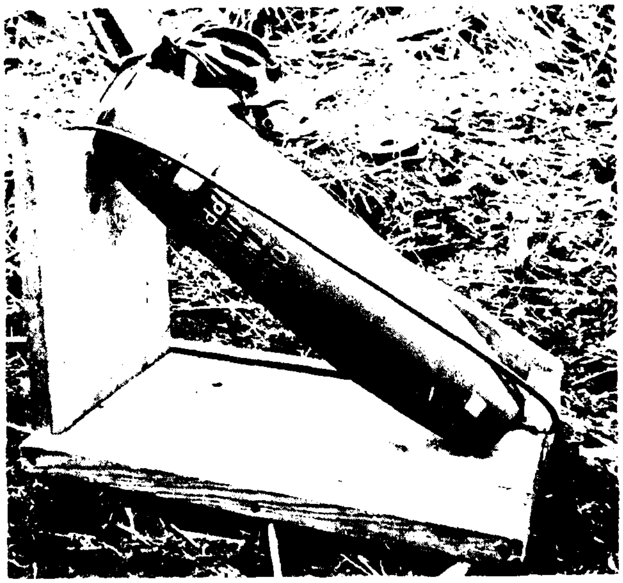


Figure 6. Wooden Stand Holding Round at 30-Degree Angle.

2.1.4 Blast Site Configurations

a. Empire Range 6 (figure 7). The blast OP at Range 6 was located approximately 400 meters from the blast areas. Test personnel were sheltered behind 1.3-centimeter steel blast shields for safety. The munitions were positioned pointing away from the OP at a 45-degree angle.

b. Pina Beach. The Pina Beach OP was located 200 to 400 meters from the blast areas.

c. Mindi Farm. The OP at Mindi Farm was located 402 meters from the blast areas.

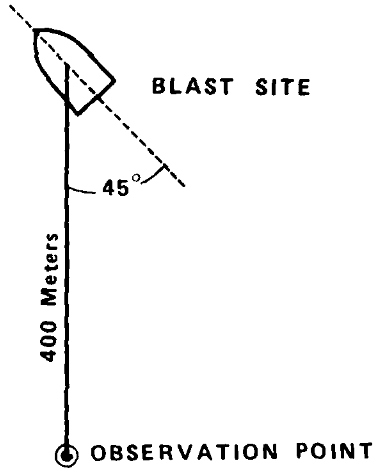


Figure 7. Observation Point Location at Range 6.

2.1.5 Data Acquisition

a. Photographic Data.

(1) At each blast site, a video tape camera and a 35-millimeter still camera were collocated at the OP to record each blast (figure 8). The still camera was synchronized to expose a frame upon detonation, and every 10 seconds thereafter, until the cloud dissipated. Video tape coverage began 10 seconds before detonation and continued until the cloud dissipated.

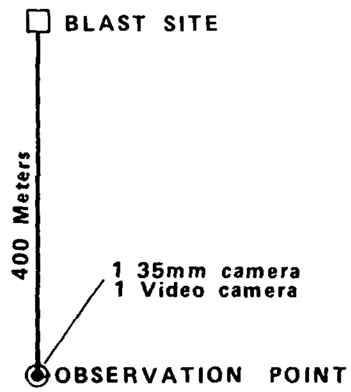


Figure 8. Camera Location.

(2) Plywood squares, 3 feet (0.9 m) by 3 feet (0.9 m), were used daily to calibrate the cameras. Two squares were mounted 10 feet (3.1 m) apart on long calibration poles (figure 9). Two such poles were placed 10 feet (3.1 m) apart downrange to provide a vertical and horizontal distance reference in all blast photographic coverage.

(3) The cameras were installed on a 20 foot (6.1 m) tower at Range 6. At Pina Beach and Mindi Farm, the cameras were tripod mounted, approximately 5 feet (1.5 m) off the ground.

(4) Black and white background targets (0.6 m by 1.2 m) were placed on poles 10 to 15 meters apart. These targets were used to evaluate the opaqueness of the cloud.

b. Surface Composition.

(1) Specialized instrumentation and procedures used to evaluate soil strength are described below:

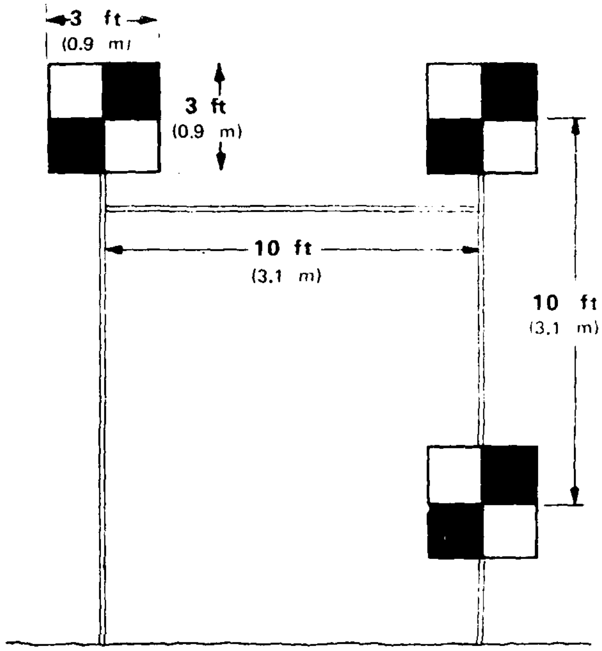


Figure 9. Plywood Squares Mounted on Calibration Poles.

(a) Cone penetrometer (figure 10): A hand-operated field instrument used to obtain an index of soil shear strength at prescribed depths. The cone penetrometer consists of a 30-degree cone with a 322.6-square-millimeter base mounted on one end of a 9.5-millimeter diameter shaft, and a proving ring with dial gage and handle mounted on the other end. The force-per-unit area required to penetrate the soil vertically is indicated on the dial inside the proving ring, and can be read while the cone is being forced into the ground by hand at a rate of 1.8 meters-per-minute.

(b) Trafficability sampler (figure 11): A piston-type sampler instrument used to obtain soft soil samples.

(c) CI reading: A measurement of soil strength (shearing resistance) obtained with the cone penetrometer. For this test, measurements were taken at the surface and at 1-inch (2.5 cm) vertical increments, to a depth of 6 inches (15.2 cm); then at 3-inch (7.6 cm) vertical increments to a depth of 18 inches (45.7 cm), and then at a depth of 24 inches (61 cm), or until the soil strength exceeded the capacity of the instrument. Fifteen sets of readings were taken and averaged for each crater site: five sets on the original surface before the blast, five sets on the rim of the crater after the blast, and five sets at the bottom of the crater. Means of CI readings, by crater and depth, are presented in table B-2.

(2) Bulk samples of 2 to 3 kilograms were taken at each blast point for laboratory analysis and identified by soil type according to the Unified Soil Classification System (USCS, reference 1). One sample was taken before the blast from the surface layer (usually 0 to 10 cm deep) at a point beyond the expected crater rim. (When it was necessary to take the sample closer to the blast point, the resulting hole was refilled with similar soil.) After the blast, another sample was taken from the bottom of the crater floor. When bulk samples were taken, they were sealed immediately in plastic or moisture-proof containers, and stored for transport to the laboratory. The data resulting from these procedures are listed in table B-3. In addition, two 100-pound (45 kg) bulk samples of soil (one from Mindi Farm and one from Range 6) were shipped to USAWES for compaction analysis tests.

(3) To collect blow-out material from the detonations, sample boards (0.6 x 1.2 m) were placed on the four points of the compass at 3-, 6-, and 9-meter intervals from center of blast. These boards were secured to the ground by

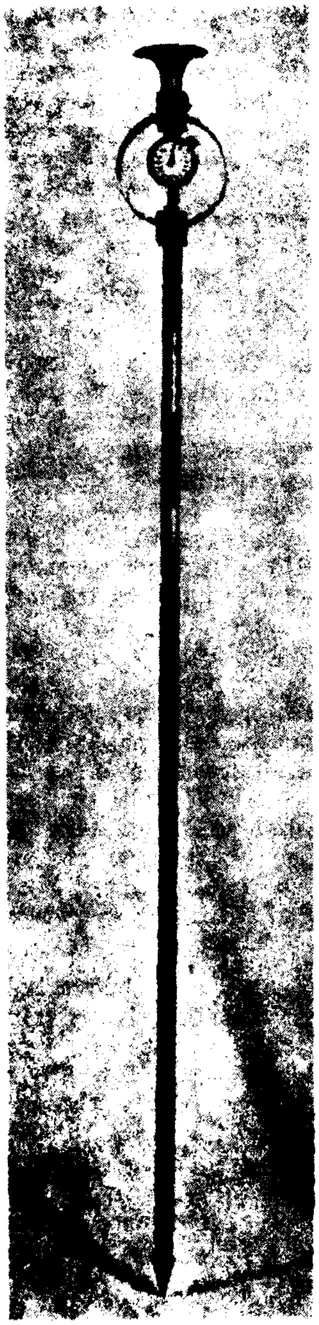


Figure 10. Cone Penetrometer.

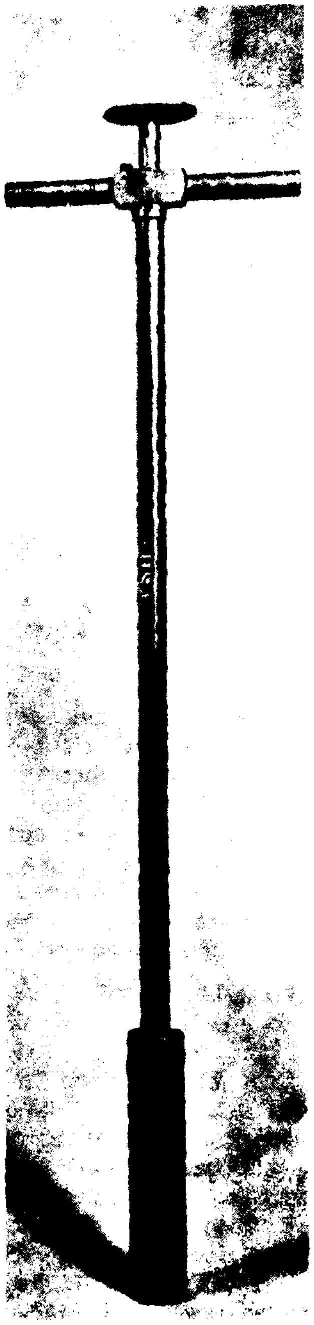


Figure 11. Trafficability Sampler.

18-inch (45.7 cm) engineer drift pins. After the blast, the debris was collected from each set of equidistant boards, sealed in plastic bags (keeping all 3-, 6-, and 9-meter material separated), and transported back to the laboratory for weighing. Grass and soil samples were weighed first together and then separately. The data resulting from analysis of blow-out material (i.e., material weight) are shown in table B-4.

(4) Moisture content and density. Two moisture samples were taken from each crater site, one at the 0- to 3-inch (0 to 7.6 cm) depth and one at the bottom of the crater. (This depth varied depending on size of blast, soil strength, and other parameters.) One density sample was taken at each crater site, also at the 0- to 3-inch (0 to 7.6 cm) depth. These data are included in table B-2.

(5) Crater measurements.

(a) Symmetric craters: The diameters of these craters were measured by laying a survey rod across the apparent center of the crater at the original ground surface (figure C-1). Vertical distances (from the rod to the crater floor) were recorded at 10-centimeter increments. Measurements were made as the craters appeared after the blast (with some loose material in the crater). In a few cases, loose material was scooped out (after the initial measurements) and the true craters were measured to determine the amount of fallback material.

(b) Asymmetric craters: The above-mentioned procedure was used. Additionally, measurements were recorded from an axis perpendicular to the first axis (figure C-1).

(c) Crater profiles, representative with/without fallback comparisons, and selected photographs, are presented in Appendix C.

c. Meteorological Data. Personnel from the Atmospheric Sciences Laboratory (ASL) Meteorological (Met) Team (Panama) recorded wind direction and velocity at each blast site OP. These readings were taken at ground level at all sites, and at the the 15-foot (4.6 m) to 18-foot (5.5 m) level from the camera tower at Range 6. Blast point meteorological data were collected at 10-minute intervals between two detonations in the morning and again in the afternoon. Rain gages were emplaced at all blast sites 24 hours before detonation. Met data are included in table B-1.

2.2 RESULTS AND ANALYSIS

a. Two basic parameters of interest--crater volume and cloud obscuration area--were calculated. Crater volumes were computed in accordance with Draft Test Operations Procedure (TOP) 4-2-830, Explosive Cratering Tests (reference 2), and are included in table B-1. The area of obscuration and the cloud center coordinates were digitized at 1-, 2-, 5-, 10-, 20-, and 40-second intervals following each detonation. A Hewlitt Packard (HP) 9830 computer was interfaced with the video display unit to digitize the cloud data. Durand's rule (reference 3) was used to compute the obscured area of the cloud (table B-5). Opaque cloud areas (through which jungle or background targets were visible) were not included in the obscured area computations.

b. All data were analyzed statistically at USATTC with an IBM 4331 computer using the Statistical Analysis System (SAS). Means were compared using analysis of variance and general linear model techniques. The variable selection procedure used in the stepwise multivariate regression was the maximum R^2 improvement technique (reference 4). Throughout this report, "not statistically significant" means not significant at the $\alpha = .05$ level.

c. Matrixes of Pearson product-moment correlation coefficients between cloud/crater variables and soil/meteorological variables are presented for TNT and 105- and 155-millimeter munitions in tables 1 through 3, respectively.

d. Stepwise multiple regression analyses were computed to investigate the interrelationships of soil/meteorological variables with cloud obscuration and crater volumes. Data from Pina Beach were not included in those analyses. Crater volumes and obscuration areas at 2-, 5-, and 10-second intervals were each treated as a dependent variable. The following independent variables were included in the analysis as potential predictor variables: Cone indexes at 0, 2 (5.1 cm), and 4 (10.2 cm) inches; moisture content at the surface; dry density; percent fines [0 to 6 inches (15.2 cm)]; Atterburg Limits at 0 to 6 inches (15.2 cm); wind speed; temperature; and relative humidity. These analyses were computed separately for each munition type.

e. For each dependent variable, the best three-variable model was chosen. The partial regression coefficients for the predictor variables for TNT and 105- and 155-millimeter munitions are presented in table 4. Probability levels, associated with the test of the null hypothesis that each population partial regression coefficient is zero, are also presented. R^2 represents the proportion of the total variability in the dependent variable that can be explained by the multiple regression model; it is presented as a measure of how well the data fit the model.

f. In general, the low significance levels and lack of consistency in the predictor variables selected by the stepwise multiple regression analyses indicate that relationships are weak between obscuration and soil parameters during the tropic wet season. More data are required before these relationships can be estimated with confidence.

g. Analysis of surface moisture and cone indexes from Empire Range 6 showed a drying effect at those areas where tents were used to cover the blast sites for several weeks before detonation. However, analysis of mean cloud areas and crater volumes did not detect a statistically significant difference in obscuration or crater volume between the covered and uncovered blast sites. The drying effect was slight and limited to the soil surface. Means and probability levels from the analysis of variance are presented in table 5. To have a matched control (uncovered area), only data from grassland sites at Range 6 were used in the analysis.

h. To compare obscured areas produced at the three main test sites, only data produced from TNT were analyzed. The means presented in table 6 show that the crater volumes at Mindi were significantly larger than the other two

TABLE 1. MATRIX OF CORRELATION COEFFICIENTS FOR TNT DATA FROM EMPIRE RANGE 6 AND MINDI SITES

Variable	Crater Volume	Crater Depth	Obscured Area Seconds After Detonation					Material Weight		
			1	2	5	10	20	3m	6m	9m
	(m^3)	(m)	(m^2)					(g)		
Cone Index (kg/cm^2)										
Surface (Before Detonation)										
Surface layer	-.327	-.264	-.348	-.320	-.222	-.160	.402	.054	.733 b/	-.021
2-inch (51 mm) layer	-.542 a/	-.543 a/	-.423	-.340	-.146	-.107	.274	.157	.274	-.347
4-inch (102 mm) layer	-.545 a/	-.615 a/	-.248	-.181	-.110	.127	.380	-.225	.246	-.396
6-inch (152 mm) layer	-.290	-.389	-.098	-.110	-.087	.023	.227	.030	-.066	-.217
Moisture Content Surface (%)	.641 b/	.586 a/	.606 a/	.582 a/	.431	.189	-.479	.231	-.105	.379
Density Dry (kg/m^3)	-.537 a/	-.464	-.434	-.467	-.284	-.264	.491	-.156	.245	-.284
Fines (%)										
0- to 6-inch (152 mm)										
Soil Layer	-.476	-.420	-.274	-.449	-.357	-.176	.277	-.124	-.062	-.444
Bottom of Crater	-.379	-.366	-.269	-.318	-.333	.023	.409	-.071	.182	-.296
Atterburg Limits										
Liquid Limit										
0- to 6-inch (152 mm)										
Soil Layer	.122	-.121	.309	.149	.142	.204	-.250	.301	-.366	.148
Bottom of Crater	.370	.314	.237	.594 a/	.607	-.070	-.473	.029	.139	.164
Plastic Limit										
0- to 6-inch (152 mm)										
Soil Layer	.504 a/	.451	.452	.332	.057	.279	-.256	.206	.119	.400
Bottom of Crater	.376	.442	.058	.350	.458	-.011	-.141	.076	.071	.188
Plastic Index										
0- to 6-inch (152 mm)										
Soil Layer	-.331	-.453	-.166	-.169	.043	-.067	.033	.025	-.345	-.236
Bottom of Crater	-.152	-.309	.182	.098	-.050	-.063	-.272	-.057	.061	-.092
Temperature (°C)	-.242	-.201	-.180	.114	.060	.325	.147	-.412	-.350	-.365
Relative Humidity (%)	.100	.088	-.007	-.294	-.231	-.543 a/	-.163	.437	.360	.326
Wind Speed at Ground (knots)	-.487	-.329	-.390	-.332	-.283	-.108	.218	-.533	-.048	-.376
Wind Speed at Tower (knots)	-.775 b/	-.501	-.419	-.339	-.493	.077	-.008	-.548	-.390	-.419
Material Weight (g)										
3 Meters	.677 b/	.355	.332	.200	.288	-.169	-.230	1.000 c/	.430	.844 c/
6 Meters	.105	.056	.155	-.039	-.023	-.200	.257	.430	1.000 c/	.332
9 Meters	.715 b/	.423	.228	.190	.321	-.058	-.055	.844 c/	.332	1.000 c/

a/ Significantly different from zero at α = .05 level
b/ Significantly different from zero at α = .01 level
c/ Significantly different from zero at α = .001 level

TABLE 2. MATRIX OF CORRELATION COEFFICIENTS FOR 105-MILLIMETER DATA FROM EMPIRE RANGE 6 AND MINDI SITES

Variable	Crater Volume	Crater Depth	Obscured Area Seconds After Detonation					Material Weight		
			1	2	5	10	20	3m	6m	9m
	(m^3)	(m)			(m^2)				(g)	
Cone Index (kg/cm^2)										
Surface (Before Detonation)										
Surface layer	-.484 a/	-.340	-.029	-.345	-.248	-.339	.259	.303	-.251	.287
2-inch (51 mm) layer	-.606 b/	-.541 a/	-.178	-.382	-.311	-.301	.105	.159	-.313	.374
4-inch (102 mm) layer	-.277	-.582 a/	-.212	-.387	-.408	-.318	.027	-.076	-.518 a/	.093
6-inch (152 mm) layer	-.375	-.632 b/	-.283	-.357	-.345	-.319	-.031	.019	-.339	.272
Moisture Content Surface (%)	.204	.642 b/	.201	.424	.402	.393	-.132	-.423	.386	-.403
Density Dry (kg/m^3)	-.199	-.582 a/	.034	-.301	-.293	-.243	.227	.012	-.619 a/	-.056
Fines (%)										
0- to 6-inch (152 mm)										
Soil Layer	-.284	-.722 b/	.043	-.279	-.236	-.355	.322	.280	-.220	.472
Bottom of Crater	-.230	-.413	-.106	-.115	-.034	-.189	.020	.048	.154	.621 a/
Atterburg Limits										
Liquid Limit										
0- to 6-inch (152 mm)										
Soil Layer	.090	.093	.353	.173	.148	.115	.198	-.434	.018	-.438
Bottom of Crater	-.248	.246	.079	.737 b/	.778 b/	.719 b/	-.197	-.328	.131	-.026
Plastic Limit										
0- to 6-inch (152 mm)										
Soil Layer	.200	.024	.369	.053	.008	-.007	.242	-.469	.163	-.394
Bottom of Crater	.074	.417	.067	.176	.178	.254	-.145	-.532 a/	-.014	-.515 a/
Plastic Index										
0- to 6-inch (152 mm)										
Soil Layer	-.276	.081	-.213	.190	.246	.220	-.204	.089	-.224	.008
Bottom of Crater	-.303	-.233	-.009	.446	.481	.345	-.015	.265	.126	.507
Temperature (°C)	-.467	-.059	-.345	-.237	-.160	-.247	-.260	.040	.150	.277
Relative Humidity (%)	.504 a/	.140	.335	.240	.165	.246	.225	-.071	-.135	-.365
Wind Speed at Ground (knots)	-.157	.291	-.436	.193	.174	.206	-.535	.192	.565 a/	.329
Wind Speed at Tower (knots)	-.307	-.405	-.547	-.133	-.005	-.073	-.493	.375	.550	.717 b/
Material Weight (g)										
3 Meters	-.177	-.444	-.386	-.149	-.078	-.107	-.137	1.000 c/	-.014	.683 b/
6 Meters	.291	.632 a/	-.080	-.182	-.218	-.271	-.160	-.014	1.000 c/	.198
9 Meters	-.351	-.543 a/	-.427	-.187	-.063	-.199	-.198	.683 b/	.198	1.000 c/

a/ Significantly different from zero at α = .05 level
b/ Significantly different from zero at α = .01 level
c/ Significantly different from zero at α = .001 level

TABLE 3. MATRIX OF CORRELATION COEFFICIENTS FOR 155-MILLIMETER DATA FROM EMPIRE RANGE 6 AND MINDI SITES

Variable	Crater Volume (m^3)	Crater Depth (m)	Obscured Area Seconds After Detonation (m^2) 1	2	5	10	20	Material Weight (g) 3m	6m	9m
Cone Index (kg/cm^2)										
Surface (Before Detonation)										
Surface layer	-.317	-.125	.096	.123	.693 b/	.482	.248	.005	.344	-.099
2-inch (51 mm) layer	-.365	-.497 a/	.164	.036	.816 c/	.702 b/	.234	-.142	.223	-.088
4-inch (102 mm) layer	-.277	-.627 b/	.253	.042	.439	.518 a/	.281	.144	.162	-.063
6-inch (152 mm) layer	-.084	-.512	.387	.104	.339	.416	.065	.315	.267	-.104
Moisture Content Surface (%)	.248	.801 c/	.233	.283	-.374	-.383	-.379	.439	-.066	.071
Density Dry (kg/m^3)	-.132	-.762 c/	.007	-.122	.415	.361	.316	-.345	.066	.052
Fines (%)										
0- to 6-inch (152 mm)										
Soil Layer	-.378	-.604 a/	.048	-.120	.681 b/	.542 a/	.157	-.358	.038	.166
Bottom of Crater	-.176 a/	-.600	-.124	-.291	.404	.338	.234	-.551 a/	-.127	.267
Atterburg Limits										
Liquid Limit										
0- to 6-inch (152 mm)										
Soil Layer	.169	.060	.448	.049	.076	.071	-.165	.396	-.129	.268
Bottom of Crater	.691 b/	.390	.292	.229	.034	.211	.143	.390	.165	-.379
Plastic Limit										
0- to 6-inch (152 mm)										
Soil Layer	-.189	.231	-.054	-.220	-.189	-.215	-.068	.092	-.234	-.068
Bottom of Crater	.630 b/	.544 a/	.247	.283	-.023	.238	.216	.179	.025	-.117
Plastic Index										
0- to 6-inch (152 mm)										
Soil Layer	.374	-.192	.496 a/	.241	.212	.245	-.114	.189	.129	.192
Bottom of Crater	-.264	-.481 a/	-.135	-.261	.029	-.237	-.247	-.030	.039	-.071
Temperature (°C)	-.012	-.547 a/	.031	-.131	.209	.220	-.027	-.368	-.042	.199
Relative Humidity (%)	-.021	.536 a/	.001	.100	-.222	-.170	-.039	.532 a/	.129	-.244
Wind Speed at Ground (knots)	.250	-.285	.021	.180	-.134	-.019	.385	-.106	-.149	.028
Wind Speed at Tower (knots)	.242	-.160	.095	.378	-.199	-.155	.370	.181	.444	-.096
Material Weight (g)										
3 Meters	-.053	.222	.200	.126	-.149	-.011	.177	1.000 c/	.235	-.177
6 Meters	.277	.086	-.112	.117	.286	.279	.661 b/	.235	1.000 c/	-.368
9 Meters	.117	.081	.259	-.190	-.230	-.155	-.268	-.177	-.368	1.000 c/

a/ Significantly different from zero at $\alpha = .05$ level
b/ Significantly different from zero at $\alpha = .01$ level
c/ Significantly different from zero at $\alpha = .001$ level

TABLE 4. PARTIAL REGRESSION COEFFICIENTS FROM THE "BEST THREE" VARIABLE MODEL

(Pina Beach Data Not Included)

TNT DATA

Crater Volume (m^3)			Obscured Area (m^2) After Detonation: 2 Seconds			5 Seconds			10 Seconds		
Variable	Regression Coefficient	Probability	Variable	Regression Coefficient	Probability	Variable	Regression Coefficient	Probability	Variable	Regression Coefficient	Probability
Intercept	1.8290	—	Intercept	-828.2	—	Intercept	-27.4	—	Intercept	9207.7	--
Temperature (°C)	-.0188	.339	Surface Moisture (%)	15.7	.005	Surface Moisture (%)	18.0	.007	Relative Humidity (%)	59.5	.028
Wind Speed (knots)	-.0348	.077	Cone Index at 152 mm (kg/cm²)	30.0	.023	Plastic Limit, 0 to 152 mm layer	-15.6	.070	Temperature (°C)	-163.0	.161
% Fines	-.0119	.029	Wind Speed (knots)	-26.9	.262	Cone Index at 102 mm (kg/cm²)	17.6	.168	Liquid Limit (%)	16.0	.252
R^2 = .542			R^2 = .575			R^2 = .503			R^2 = .449		

105-MILLIMETER DATA

Variable	Regression Coefficient	Probability	Variable	Regression Coefficient	Probability	Variable	Regression Coefficient	Probability	Variable	Regression Coefficient	Probability
Intercept	.34399	—	Intercept	8573.3	—	Intercept	861.8	--	Intercept	-595.8	--
Cone Index at 51 mm (kg/cm²)	-.01618	[illegible]	Surface Moisture (%)	6.3	.220	Plastic Index, 0 to 152 mm	21.1	.341	Surface Moisture (%)	15.8	.449
Plastic Index, 0 to 152 mm layer	-.00968	.003	Temperature (°C)	-198.3	.445	Temperature (°C)	-23.0	.619	Dry Density (kg/cm³)	.74	.571
Dry Density (kg/m³)	.00016	.057	Relative Humidity (%)	-36.0	.505	Cone Index at 102 mm (kg/cm²)	-11.3	.439	Plastic Index, 0 to 152 mm	-18.3	.414
R^2 = .765			R^2 = .260			R^2 = .273			R^2 = .239		

155-MILLIMETER DATA

Variable	Regression Coefficient	Probability	Variable	Regression Coefficient	Probability	Variable	Regression Coefficient	Probability	Variable	Regression Coefficient	Probability
Intercept	2.4898	—	Intercept	629.99	--	Intercept	-444.5	--	Intercept	-1058.7	--
Cone Index at 51 mm (kg/cm²)	-.0226	.003	Surface Moisture (%)	9.75	.155	Cone Index at 51 mm (kg/cm²)	25.6	.001	Cone Index at 51 mm (kg/cm²)	85.0	.014
Plastic Limit, 0 to 152 mm	-.0211	.012	Plastic Limit, 0 to 152 mm	-10.80	.199	% Fines	18.2	.034	Surface Moisture (%)	10.4	.156
Liquid Limit, 0 to 152 mm	-.0148	.107	Dry Density (kg/cm³)	.72	.313	Temperature (°C)	-33.1	.004	Cone Index at 51 mm (kg/cm²)	-39.1	.054
R^2 = .607			R^2 = .288			R^2 = .849			R^2 = .609		

TABLE 5. MEANS AND SIGNIFICANCE LEVEL FOR COVERED AND UNCOVERED GRASSLAND SITES AT EMPIRE RANGE 6

Variable	Covered	Uncovered	Significance
Moisture Content Surface (%)	34.8	41.0	<.01
Cone Index (kg/cm^2) (Before Detonation)			
Surface Layer	8.1	4.7	<.01
51-mm Layer	15.2	12.2	<.05
102-mm Layer	21.2	21.6	NS
Crater Volume (m^3)	0.331	0.332	NS
Obscured Area (m^2) (After Detonation)			
1 Second	83	136	NS
2 Seconds	161	197	NS
5 Seconds	293	258	NS
10 Seconds	368	448	NS
20 Seconds	330	217	NS
Material Weight (g)			
3 Meters	4,666	5,055	NS
6 Meters	1,786	1,283	NS
9 Meters	480	617	NS

NS = Not Significant

TABLE 6. MEANS AND SIGNIFICANCE LEVEL OF SOIL AND CLOUD DATA

(For TNT Only)

	SITE			
Variable	Mindi	Pina	Range 6	Significance
Number of Craters	4	12	15	—
Crater Volume (m^3)	0.553	0.283	0.271	<.001
Time After Detonation (sec)	Obscured Area (m^2)			
1	211	186	96	<.05
2	474	291	228	<.05
5	581	475	370	NS
10	805	506	666	NS
20	0	51	609	<.05

Table 6 (cont)

Variable	Mindi	Pina	Range 6	Significance
Location	Material Weight (g)			
3 Meters	7,078	3,991	4,650	NS
6 Meters	1,437	605	1,435	NS
9 Meters	591	179	296	<.01
Moisture Content Surface (%)	66.7	9.9	37.8	<.001
Density Dry (kg/m^3)	868	1,607	1,132	<.001
Fines (%)				
0- to 152-mm Soil Layer	61	6	71	<.001
Bottom of Crater	60	6	71	<.001
Atterburg Limits				
Liquid Limit				
0- to 152-mm Soil Layer	61.2	—	55.6	NS
Bottom of Crater	58.5	—	50.6	<.05
Plastic Limit				
0- to 152-mm Soil Layer	49.5	—	36.6	.01
Bottom of Crater	45.0	—	32.4	.01
Plastic Index				
0- to 152-mm Soil Layer	11.3	—	18.9	NS
Bottom of Crater	13.3	—	18.1	NS
Cone Index (kg/cm^2)				
Surface (Before Detonation)				
Surface Layer	4.2	1.2	6.2	<.01
51-mm Layer	7.2	4.2	12.8	<.001
102-mm Layer	10.0	7.4	20.8	<.001
Rim (After Detonation)				
Surface Layer	1.5	1.0	5.6	<.001
51-mm Layer	3.9	3.2	12.1	<.001
102-mm Layer	5.5	6.7	17.5	<.001
Bottom of Crater				
Surface Layer	2.0	2.0	10.1	<.001
51-mm Layer	12.6	4.7	23.5	<.001
102-mm Layer	3.2	7.3	33.9	<.001

Table 6 (concluded)

Variable	SITE Mindi	Pina	Range 6	Significance
Met Data	Material Weight (g)			
Temperature (°C)	28.8	29.5	29.7	<.001
Relative Humidity (%)	84	80	78	NS
Wind Speed at Ground (knots)	3.3	3.4	3.9	NS

NS = Not Significant

sites. This resulted in proportionately larger fallout material at 3, 6, and 9 meters. Initial cloud sizes were larger at Mindi because of more blowout. However, as shown in figure 12, no obscured area remained at the Mindi site 20 seconds after the blast. The soil at Mindi was wetter, not as dense when dry, and had lower cone indexes and plastic limits. The crater volumes and obscured areas at Pina Beach were comparable to those at Empire Range 6, but the weight of the blow-out material at 3, 6, and 9 meters was less. Analyses of the crater volumes, obscured areas, and weight of blow-out material at Pina Beach did not detect a consistent effect of beach vegetation on these variables.

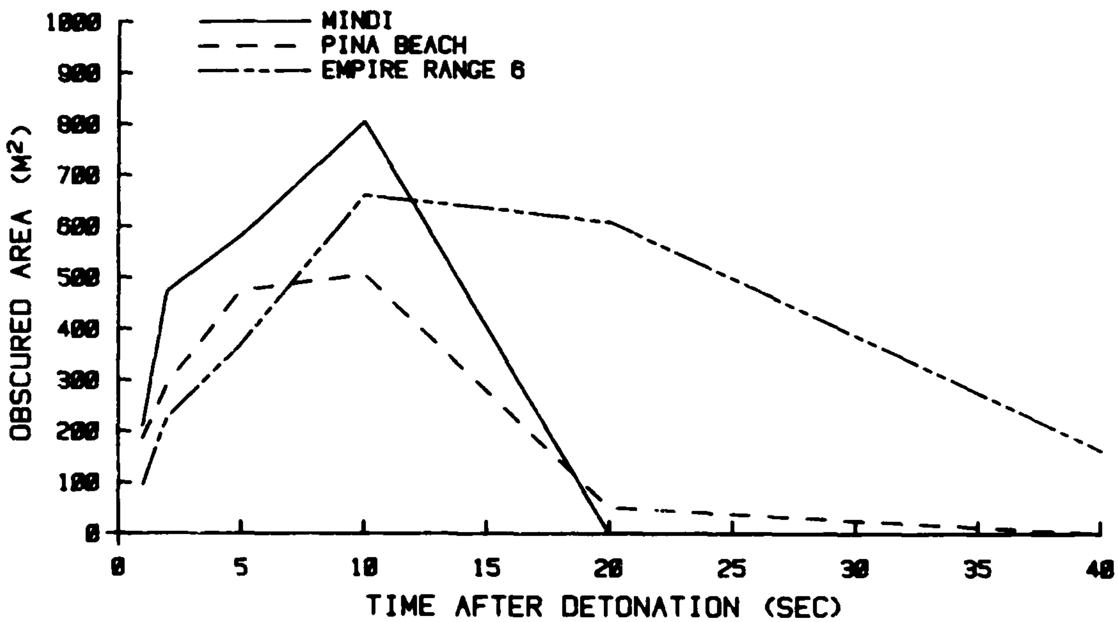


Figure 12. Obscured Area versus Time (TNT Data).

i. In comparing the effects of three munition types and levels of vegetation (uncut grass, cut grass, and bare soil), only data from Mindi and Empire Range 6 grass sites were analyzed. Grassland results (main effect probability levels) from the analysis of variance are presented in tables 7 and 8.

TABLE 7. MEANS AND SIGNIFICANCE LEVEL OF CRATER AND CLOUD DATA FROM MINDI FARM AND RANGE 6, BY MUNITIONS TYPE

Munition	Number of Craters	Crater Volume	Obscured Area Seconds After Detonation 1	2	5	10	20	Weight of Blowout Material 3m	6m	9m
		(m^3)			(m^2)				(g)	
TNT	16	0.339	130	308	458	774	475	5,257	1,436	370
105mm	12	0.210	87	157	187	171	18	2,914	834	336
155mm	15	0.531	143	177	215	259	76	7,176	2,313	974
Significance	—	<.001	NS	<.05	<.001	<.001	NS	<.001	NS	<.01

NS = Not Significant.

TABLE 8. MEANS AND SIGNIFICANCE LEVEL OF CRATER AND CLOUD DATA FROM MINDI FARM AND RANGE 6, BY VEGETATION LEVEL

Vegetation Level	Number of Craters	Crater Volume	Obscured Area Seconds After Detonation 1	2	5	10	20	Weight of Blowout Material 3m	6m	9m
		(m^3)			(m^2)				(g)	
Bare Soil	15	0.369	129	240	353	589	153	4,706	1,761	586
Cut Grass	14	0.340	134	268	290	406	287	4,568	1,216	469
Uncut Grass	14	0.369	103	151	246	272	190	6,022	1,594	609
Significance	—	NS	NS	<.01	NS	<.05	NS	NS	NS	NS

NS = Not Significant.

j. These results show that while the 155-millimeter ammunition creates larger craters and produces more blowout material, TNT produces the greater obscured areas (figure 13). This is because of the black smoke produced by TNT, rather than because of suspended particles. The means show less obscuration from munitions detonated in the high, uncut grass compared to those

detonated in bare soil or cut grass. The high grass probably had a dampening effect on dust and dirt that, otherwise, would have been suspended in the air. However, dust and dirt did not appear to contribute greatly to obscuration during this study—smoke from the TNT and munition charges contributed most to obscuration.

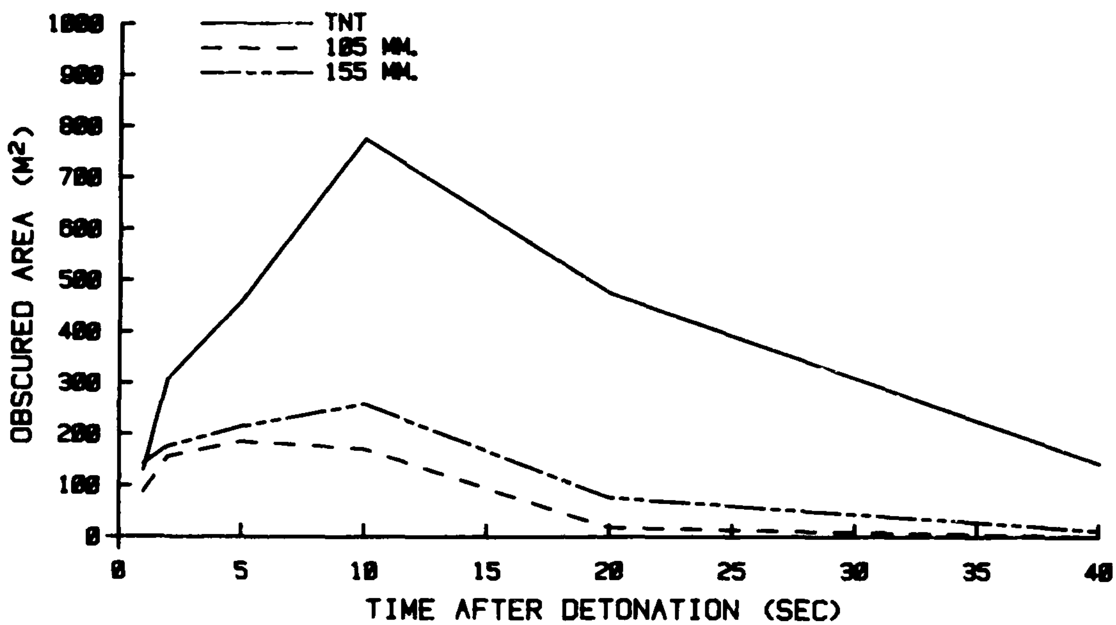


Figure 13. Obscured Area versus Time (Mindi and Empire Range 6 Data).

SECTION 3. APPENDIXES

APPENDIX A. TEST DIRECTIVE AND METHODOLOGY INVESTIGATION PROPOSAL

(COPY) Dr. Haverland/ldm/mjp/AUTOVON: 283-2170

DEPARTMENT OF THE ARMY
HEADQUARTERS, US ARMY TEST AND EVALUATION COMMAND
ABERDEEN PROVING GROUND, MARYLAND 21005

DRSTE-AD-M

SUBJECT: Directive, Environmental Realism in Battlefield Obscuration, TRMS No. 7-CO-RD0-TT1-004

Commander
US Army Tropic Test Center
ATTN: STETC-MTD-M
APO Miami 34004

1. Reference TECOM Regulation 70-12, dated 1 June 1973.

2. This letter and attached STE Forms 1188 and 1189 (Inclosure 1) constitute a directive for the subject investigation under the TECOM Methodology Improvement Program (MIP) 1T665702D625.

3. The MIP at Inclosure 2 is the basis for headquarters approval of the subject investigation.

4. Special Instructions:

a. All reporting will be in consonance with paragraph 9 of the reference. The final report, when applicable, will be submitted to this headquarters, ATTN: DRSTE-AD-M, in consonance with Test Event 53, STE Form 1189.

b. Recommendations concerning new TOPs or revisions to existing TOPs will be included as part of the recommendation section of the final report. Final decision on the scope of the TOP effort will be made by this headquarters as a part of the report approval process.

c. The utilization of the funds provided to support the final investigation is governed by the rules of incremental funding.

d. The addressee will determine whether any classified information is involved and will assure that proper security measures are taken when appropriate.

DRSTE-AD-M
SUBJECT: Directive, Environmental Realism in Battlefield Obscuration, TPMS No. 7-CO-RDO-TT1-004

e. Upon receipt of this directive, test milestone schedules will be immediately reviewed in light of known other workload and projected available resources, in accordance with provisions of paragraph 2-4 of TECOM Regulation 70-8. If rescheduling is necessary, this headquarters, ATTN: DRSTE-TO-O, will be notified by first indorsement, not later than 20 May 1980. If schedules can be met, a P6 entry will be made directly into TRMS master file by that date.

f. Consideration should be given to gathering additional data concerning the correlation between the obscuration caused by the explosions and the environmental characteristics since this area is of primary concern. If US Army Tropic Test Center considers it possible to collect such data in conjunction with the planned effort, please inform this headquarters, ATTN: DRSTE-AD-M by close of business 20 May 80 of your plans in this area and of additional funding requirement for FY80 and beyond. DPG, which is heavily involved in obscuration, should be contacted concerning air sampling procedures in order to assure proper coordination. The DPG POC is Dr. Lothar Salomon, AUTOVON: 789-5416.

g. The Methodology Improvement Division Point-of-Contact is Dr. Edgar M. Haverland, ATTN: DRSTE-AD-M, AUTOVON 283-2170/2375.

FOR THE COMMANDER:

2 Incl
as

/s/Sidney Wise
/t/SIDNEY WISE
C, Meth Imprv Div
Analysis Directorate

1. TITLE. Environmental Realism--Battlefield Obscuration

2. CATEGORY. Environmental Testing

3. INSTALLATIONS. US Army Tropic Test Center
APO Miami 34004

US Army Engineer Waterways Experiment Station
Vicksburg, MS 39180

4. PRINCIPAL INVESTIGATORS. Mr. Robert H. Johnson
Materiel Test Division
AUTOVON: 313-285-4101

Mr. James Mason
AUTOVON: 601-634-2601

5. STATEMENT OF THE PROBLEM. A fundamental gap in knowledge exists in the relationship between obscurant production during combat activities and the type and condition of soils encountered in heavily vegetated tropic environments.

6. BACKGROUND.

a. The need for more realistic models of the battlefield has been stressed in the recent past. The performance of many modern weapon systems can be adversely affected by heavy concentrations of dust and smoke in the air. A systematic effort has been underway to assess such effects both in the field and through mathematical models. Basic models describing such physical phenomena as scattering and absorption of radiation have been applied to battlefield scenarios characterizing a wide range of conditions. The results have been used to produce parametric models for obscured conditions typical of certain geographic or climatic regions. Engineering models have also been developed to describe the performance of a number of weapon systems, and these either have or will incorporate such parametric models in most cases.

b. At this point, the model approach serves the needs of the engineering community in the development and, to some extent, the evaluation of such weapons systems. A further step is desired. That is the use of the models in determining effective deployment of weapons systems. For this, a new regime of information and assessment is needed. Now it is not enough to treat "general" or "typical" conditions; one must deal with specific geography and specific climates. A new range of base data is identified in these terms. Also, a new user of the model enters the picture—the field commander and field engineer.

7. GOAL. The aim of this investigation is to obtain information concerning the dust produced by explosives on different types of tropic soils with varying conditions.

8. DESCRIPTION.

a. The test will consist of detonations of a number of rounds of 155-millimeter and 105-millimeter ammunition, and of TNT in static configurations on or just beneath the soil surface. Each detonation will be carefully logged and documented by photographic and physical methods to allow analysis of the growth and extent of the cloud, its correlation with meteorological conditions, and the effects of soil type, moisture, vegetation, etc. on its obscurant features. Specific measurements to be made and methods used are further described below.

b. Pretest survey and blast site location--Phase I.

(1) The target area is to be thoroughly tested to establish range and distribution of soil strength and moisture content over the area, and to locate inhomogeneities or pockets. Layered structure in cone index (CI) data should also be an object of the search. This is best done by initially setting a grid system of about 10-meter by 10-meter intervals over the target area. Intersection points are then marked by stakes and sampling done at those markers. Blast locations will be chosen for these points.

(2) Blast locations should be chosen to yield an adequate coverage of the range of conditions existing at the site and to allow meaningful comparison of results. That is, if moisture and CI both vary markedly the extremes would need to be tested, and an effort should be made to locate sites indicative of the four possible combinations (i.e., high MC-low CI, high MC-high CI, low MC-high CI and low MC-low CI). Similar guidelines will apply to other variables.

(3) At each combination of conditions a significant sampling is necessary. A minimum of four detonations at each is considered advisable here. Of course, if there are too many variables, some must be overlooked. For this purpose, a hierarchy is necessary in the importance of the soil variables.

Soil classification (visual).
Soil moisture.
Cone index (prefereably remoulding CI).
Plastic index.

This list gives the order of importance anticipated at present. Soil class here would be established visually. Variations in color, texture, consistency and structure are to be observed. Conditions that would produce wide lateral variations in the space occupied by a water should be avoided. Vertical variations should be carefully noted. Differences in texture and composition should also be carefully noted and if significant differences exist they should be covered in the tests.

(4) Soil moisture is next in importance and should be assessed at the surface and below the soil or A-horizon, but not deeper than the anticipated crater depth (about 1/2 meter for 155-millimeter and 3/10 meter for 105-millimeter rounds). CI has not so far proven very significant; however, it is believed that it should be third in importance. Plastic index is considered equally important, but since it is a laboratory test and not readily

determined in the field, it is given lower significance. Any obvious variations in plasticity, however, should be considered in locating blast points.

(5) Bulk samples of 2 to 3 kilograms should be taken at each blast site for laboratory analysis. One is taken from the surface layer (usually 0-10 centimeter) before the blast at a point that will be beyond the crater rim. (If it is necessary to take the sample nearer the blast point, the resulting hole should be refilled with similar material to the original surface.) Another sample will be taken at the depth of the crater floor (see under post-test measurements). Bulk samples are to be sealed in plastic or sufficiently moisture-proof containers when they are taken and stored for transport to the laboratory.

c. Test phase data—Phase II.

(1) Observations during tests will consist of photographic coverage, sampling pans for collection of fallback material and samplers to collect cloud debris. This latter method is yet to be determined but may be pans, adhesive strips or filtered air-flow devices. The overall objective is to determine the mass of material in the cloud and in the initial fallback around the crater. The volume, growth and density of the cloud will be judged from the photography.

(2) The sampling pans for fallback are to be placed at successive distances from the blast center (point zero) of 1-1/2 R, 2R, 3R and 4R where R is the anticipated crater radius (1 meter for 155-millimeter and 0.75 meter for 105-millimeter rounds). Enough pans should be used to insure a representative sampling of distribution around the crater.

(3) Photography may be used in two ways. Simple documentation and cloud expansion data may be obtained with two cameras operated as a stereo pair or at right angles (the more preferable). Distances from and angles to point zero and to several reference points must be carefully recorded, and the lens parameters and fields of view are also necessary. For full camera coverage, stereo cameras are set up on opposing sides of the target area, and a third pair is set at approximately a right angle to these for control. In all arrangements, it is necessary to operate all cameras simultaneously and voice communication between camera sites is highly desirable for this.

(4) The operations to be performed at the site following each shot are the recording of crater dimensions, CI at the rim and bottom of the crater, and sample collection. The crater depth and diameters at right angles are measured at the level of the original surface. Depth is taken from this level to the visible floor of the crater. CI should be taken just outside the rim beginning at the original surface. Any throw-out material should be scooped clear.

(5) Samples from the pans may be weighed at the site or bagged for later weighing. All samples from equal distances are added together. If air samplers are used, these will be analyzed by electronic microscopy and should

be handled accordingly. There is no need to keep the individual samples separate unless they were taken at quite different times in the cloud history.

(6) Moisture content at the depth of each crater should also be determined. This is done by scooping out a section of wall to obtain a sample of original soil.

d. Laboratory analysis--Phase III.

(1) It is usually not practical to fully analyze each soil sample. Size gradations by sieve and hydrometer analysis should be made on a reasonable sampling of the site material. More surface samples than depth samples should receive this analysis. The samples chosen should provide a good representation of the area covered in testing. A total of ten samples with six from the surface would be a minimum.

(2) Plastic and liquid index and remoulded CI should be obtained from each crater site. Here again, the surface is regarded as more important than depth (in about the same ratio). Organic content should be measured for a representative sampling for sparsely vegetated sites. For soil, the sampling should also be representative and should include most counts.

e. Health Hazard Assessment. Participants will be within normal duty limits under conditions in which neither informed participation nor volunteer participation is required, i.e., no health hazards have been identified in this MIP. Similar activities in the past have not revealed any health hazards.

9. PROGRESS. New investigation.

10. JUSTIFICATION.

a. This investigation will support ongoing work at US Army Engineer Waterways Experiment Station (USAWES) under DA Project No. 4A76270AT42 entitled "Improved Environmental Realism for Battlefield Simulation". This investigation conforms with the guidelines stated in Memorandum of Understanding (MOU) between the Office of the Chief of Engineers and the Commander, US Army Test and Evaluation Command regarding tropic environmental research.

b. Dollar Savings. The ultimate use of the results obtained in this investigation will be to develop more realistic models of the battlefield. Parametric models, for obscured conditions typical of heavily vegetated tropic environments, will undoubtedly lead to savings in cost of combat development experimentation. Estimation of savings cannot be approximated at this time.

c. Workload. As stated in 10a above, this is a cooperative project in Battlefield Obscuration.

d. Recommended TRMS Priority. Priority 1.

e. Association with Requirement Documents. Not applicable.

11. RESOURCES.

a. Financial.

(1) Funding breakdown:

Dollars (Thousands)

	FY 80		FY 81	
	In-House	Out-of-House	In-House	Out-of-House
Personnel Compensation				
Travel	1.0		1.0	
Contractural Support		5.5		2.0
Consultants and Other Services				
Materials and Supplies	2.0		1.0	
Equipment	2.0		0.5	
Subtotal	5.0	5.5	2.5	2.0
FY Total	10.5		4.5	

(2) Explanation of Cost Categories:

(a) Personnel Compensation. Not applicable.

(b) Travel. Two trips to USAEWES for initial detailed planning and final reporting.

(c) Contractural Support. Support work at field sites and in the laboratories is accomplished by service contract personnel.

(d) Consultant and Other Services. Not applicable.

(e) Materials and Supplies. For use in detailed site measurements and lab soil analysis.

(f) Equipment. For minor soil and field aids.

b. Anticipated Delays. Requisitioning of 105-millimeter HE ammunition (60 rounds approximately) and 155-millimeter rounds (30 approximately) may delay Test Phase II. Support of the 193d Infantry Brigade (Panama) Artillery and Explosives Ordnance Detachment (EOD) units will have to be requested.

c. Obligation Plan.

	FQ	3	4	1	TOTAL
Obligation Rate (Thousands)		5.0	7.0	3.0	15.0

d. In-House Personnel.

		FY 80 Man-Hours	
	No.	Required	Available
Engr Tech (GS0802)	1	400	400
Phys Science Admin (GS1301)	1	50	50
Math Stat (GS1529)	1	250	250
QA Specialist (GS1910)	1	100	100
ORSA (GS1515)	1	200	200
Photo-TV Spec (GS1060)	2	300	300
		1300	1300

12. INVESTIGATION SCHEDULE.

	FY 80					FY 81		
	M	J	J	A	S	O	N	D
In-House	--R							

Symbols: ----- Active investigation work
R Final Report at HQ TECOM

13. ASSOCIATION WITH TOP PROGRAM. Not applicable.

/s/Frank S. Mendez
/t/FRANK S. MENDEZ
C, Materiel Test Division

(END COPY)

APPENDIX B. DATA TABLES

TABLE B-1. CRATER DATA, SITE DESCRIPTIONS, AND METEOROLOGICAL DATA

CRATER	SITE	TIME	DATE	GRASS TYPE	PREVIOUS SITE EXPOSURE	VEGETATION	MUNITION	TEMPERATURE (°C)	RELATIVE HUMIDITY (%)	TOTAL RAINFALL (mm)	WIND SPEED (knots)	AZIMUTH a/ (°)	WIND DIRECTION (°)	CRATER VOLUME (m³)	VOLUME WITHOUT FALLBACK (m³)
1	Range 6	1445	280780	G	U	HG	TNT	27.2	96	0	7	281	245	0.15	—
2	Range 6	1018	290780	P	U	HG	TNT	28.5	77	5	6	280	305	0.29	—
3	Range 6	1109	290780	G	U	BS	TNT	30.3	73	5	5	282	270	0.22	0.31
4	Range 6	1230	290780	G	U	CG	TNT	31.2	71	5	2	282	220	0.21	—
5 b/	Range 6	1354	200780	P	U	CG	TNT	32.8	67	5	2	280	300	0.30	—
6	Range 6	0920	300780	P	U	HG	105	29.7	79	16	4	282	300	0.24	—
7	Range 6	1025	300780	G	U	HG	105	29.7	78	16	4	282	300	0.17	—
8	Range 6	1143	300780	G	U	CG	105	30.3	72	16	6	282	260	0.18	0.26
9	Range 6	1320	300780	G	U	HG	155	30.5	74	16	7	283	300	0.67	—
10	Range 6	1430	300780	P	U	HG	155	28.9	89	16	2	280	280	0.34	—
11	Range 6	0915	310780	G	U	BS	105	27.4	89	0	2	282	330	0.37	0.40
12	Range 6	1005	310780	P	U	BS	105	28.9	81	0	0	278	—	0.20	—
13	Range 6	1110	310780	P	U	CG	105	32.1	69	0	1	278	270	0.17	0.24
14	Range 6	1200	310780	G	U	BS	155	29.9	77	0	3	281	295	0.50	—
15	Range 6	1320	310780	P	U	BS	155	28.3	88	0	1	280	305	0.32	0.50
16	Range 6	1500	310780	G	U	CG	155	24.1	100	1	3	283	330	0.72	—
17	Range 6	0840	010880	P	U	BS	TNT	27.0	85	8	2	280	60	0.39	0.51
18	Range 6	0920	010880	P	U	CG	TNT	26.9	84	10	1	281	280	0.42	—
19	Range 6	1010	010880	P	U	CG	155	28.9	82	10	1	282	240	0.44	0.49
20	Range 6	1055	010880	M	U	LC	155	28.0	81	10	3	280	310	0.76	—
21	Pina	1237	180880	M	U	DS	TNT	29.6	80	14	5	262	286	0.29	—
22	Pina	1329	180880	M	U	DS	TNT	32.7	71	14	4	262	309	0.34	—
23	Pina	1430	180880	M	U	BL	TNT	32.5	74	14	3	262	292	0.22	—
24	Pina	1512	180880	M	U	BL	TNT	31.5	75	14	3	261	273	0.24	—
25	Pina	1042	180880	M	U	O	TNT	28.8	83	48	3	258	295	0.17	—
26	Pina	1118	190880	M	U	O	TNT	29.6	75	48	2	258	170	0.30	—
27	Pina	1158	190880	S	U	O	TNT	27.8	81	48	3	258	310	0.20	—
28	Pina	1253	190880	S	U	WS	TNT	28.0	85	50	1	267	300	0.37	—
29	Pina	1316	190880	S	U	WS	TNT	28.7	82	50	4	267	295	0.35	—

Table B-1. Crater Data, Site Descriptions, and Meteorological Data (cont)

CRATER	SITE	TIME	DATE	GRASS TYPE	PREVIOUS SITE EXPOSURE	VEGETATION	MUNITION	TEMPERATURE (°C)	RELATIVE HUMIDITY (%)	TOTAL RAINFALL (mm)	WIND SPEED (knots)	AZIMUTH a/ (°)	WIND DIRECTION (°)	CRATER VOLUME (m³)	VOLUME WITHOUT FALLBACK (m³)
31	Pina	1415	190880	S	U	O	TNT	29.0	85	50	4	258	275	0.29	—
31	Pina	1458	190880	M	U	HG	TNT	28.[illegible]	85	50	4	252	275	0.39	—
32	Pina	1530	190880	M	U	HG	TNT	28.1	80	50	5	252	235	0.24	—
33	Range 6	1129	250880	P	C	BS	105	32.2	65	0	6	281	155	0.19	—
34	Range 6	1203	250880	P	C	CG	105	33.3	60	0	3	278	130	0.16	—
35	Range 6	1319	250880	P	C	HG	105	31.2	72	0	4	278	140	0.30	0.34
36	Range 6	1407	250880	P	C	BS	155	32.3	69	0	4	283	155	0.41	—
37	Range 6	1515	250880	P	C	CG	155	32.2	69	0	6	275	110	0.65	—
38	Range 6	1555	250880	P	C	HG	155	32.6	71	0	3	274	110	0.66	0.71
39	Range 6	0957	260880	G	C	BS	105	32.1	66	0	2	282	350	0.20	—
40	Range 6	1044	260880	G	C	CG	105	32.0	68	0	5	283	320	0.10	—
41	Range 6	1142	260880	G	C	HG	105	31.7	67	0	6	281	280	0.17	—
42	Range 6	1236	260880	P	C	BS	TNT	32.1	68	0	5	272	270	0.23	0.31
43	Range 6	1414	260880	P	C	CG	TNT	31.0	75	0	6	280	250	0.25	0.31
44	Range 6	1452	260880	P	C	HG	TNT	28.1	93	0	3	279	290	0.26	—
45	Range 6	1544	260880	G	C	BS	TNT	28.3	90	1	6	284	240	0.21	—
46	Range 6	1627	260880	G	C	BS	155	28.1	86	0	3	285	290	0.63	—
47	Range 6	0929	270880	G	C	HG	TNT	26.9	90	1	3	281	290	0.28	0.43
48	Range 6	1012	270880	G	C	HG	155	28.3	79	1	3	274	290	0.34	—
49	Range 6	1108	270880	G	C	CG	155	30.0	73	1	3	278	290	0.57	0.54
50	Range 6	1151	270880	G	C	CG	TNT	31.7	71	1	5	278	210	0.35	—
51	Range 6	1322	270880	O	U	LC	TNT	31.9	65	1	3	281	320	0.29	—
52	Range 6	1355	270880	O	U	LC	TNT	31.1	71	1	2	281	250	0.22	—
53	Range 6	1440	270880	O	U	LC	105	30.3	77	1	3	283	280	0.28	—
54	Range 6	1534	270880	O	U	LC	105	28.3	85	1	6	279	300	0.19	—
55	Range 6	1611	270880	O	U	LC	155	27.8	84	1	3	281	290	0.22	—
56	Range 6	1701	270880	O	U	LC	155	26.1	86	1	5	278	270	0.41	—
57	Mindi	1250	141080	O	U	BS	TNT	—	—	14	—	73	—	0.72	—
58	Mindi	1339	141080	G	U	CG	TNT	29.7	82	14	3	74	—	0.30	—

Table B-1. Crater Data, Site Descriptions, and Meteorological Data (concluded)

CRATER	SITE	TIME	DATE	GRASS TYPE	PREVIOUS SITE EXPOSURE	VEGETATION	MUNITION	TEMPERATURE (°C)	RELATIVE HUMIDITY (%)	TOTAL RAINFALL (mm)	WIND SPEED (knots)	AZIMUTH a/ (°)	WIND DIRECTION (°)	CRATER VOLUME (m³)	VOLUME WITHOUT FALLBACK (m³)
59	Mindi	1454	141080	G	U	HG	TNT	28.8	83	14	5	75	—	0.38	0.53
60	Mindi	1546	141080	G	U	HG	TNT	28.0	86	14	2	77	—	0.81	—
61	Mindi	1043	151080	G	U	CG	105	29.0	82	38	6	73	270	0.17	—
62	Mindi	1126	151080	G	U	BS	105	30.0	79	38	4	75	250	0.24	—
63	Mindi	1200	151080	G	U	HG	105	30.6	75	38	7	76	270	0.29	0.33
64	Mindi	1348	151080	G	U	BS	155	25.0	96	65	1	75	280	0.70	—
65	Mindi	1442	151080	G	U	HG	155	25.8	95	65	4	75	300	0.56	—
66	Mindi	1526	151080	G	U	CG	155	24.7	98	65	3	73	270	0.45	0.63

a/ Azimuth of line of site from observation point to blast site.

b/ Because video coverage was lost, crater 5 was reshot as crater 18.

Legend:

C = Covered
G = Gynerium sagittatum
M = Morning Glory
O = Other
P = Panicum sp (1-2 m tall)
S = Spider Lily
U = Uncovered
BL = Black Sand
BS = Bare Soil
CG = Cut Grass
DS = Dry Sand (white)
HG = High Grass
LC = Low Canopy
LG = Low Grass
WS = Wet Sand

TABLE B-2. SOILS ANALYSIS DATA

Average Cone Index at Depth, pounds-per-square-inch (kilograms-per-square-centimeter)

Crater Number	Crater Depth (meters)	Ground Surface (before detonation) 0 in. (0 mm)	2 (51)	4 (102)	6 (152)	9 (229)	12 (305)	15 (381)	18 (457)	24 (610)	Crater Rim 0 in. (0 mm)	2 (51)	4 (102)	6 (152)	9 (229)	12 (305)
1	.29	48 (3.4)	155 (10.9)	228 (16.0)	306 (21.5)	608 (42.7)	--	--	-	-	[illegible] (7.2)	216 (15.2)	256 (18.0)	--	--	--
2	.41	58 (4.1)	195 (13.7)	305 (21.4)	329 (23.1)	--	--	--	--	--	55 (3.9)	112 (7.9)	169 (11.9)	294 (20.7)	544 c/ (38.2 c/)	650 c/ (45.7 c/)
3	.24	82 (5.8)	208 (14.6)	362 (25.5)	447 c/ (31.4 c/)	675 c/ (47.5 c/)	750 c/ (52.7 c/)	c/	c/	c/	90 (6.3)	190 (13.4)	312 (21.9)	575 c/ (40.4 c/)	--	--
4	.34	45 (3.2)	100 (7.0)	230 (16.2)	450 (31.6)	600 (42.2)	750 c/ (52.7 c/)	c/	c/	c/	50 (3.5)	120 (8.4)	245 (17.2)	662 c/ (46.5 c/)	750 c/ (52.7 c/)	c/
6	.24	55 (3.9)	128 (9.0)	228 (16.0)	356 (25.0)	550 c/ (38.7 c/)	586 c/ (41.2 c/)	750 c/ (52.7 c/)	c/	c/	51 (3.7)	105 (7.4)	160 (11.2)	323 c/ (22.7 c/)	260 c/ (18.3 c/)	467 c/ (32.8 c/)
7	.16	55 (3.9)	170 (12.0)	288 (20.2)	388 (27.3)	750 c/ (52.7 c/)	c/	c/	c/	c/	50 (3.5)	135 (9.5)	210 (14.8)	250 (17.6)	400 (28.1)	625 c/ (43.9 c/)
8	.22	85 (6.0)	275 (19.3)	383 (26.9)	500 (35.2)	—	—	—	—	—	68 (4.8)	180 (12.7)	300 (21.1)	383 (26.9)	467 (32.8)	517 (36.3)
9	.24	53 (3.7)	180 (12.7)	425 (29.9)	583 c/ (41.0 c/)	750 c/ (52.7 c/)	c/	c/	c/	c/	45 (3.2)	183 (12.9)	273 (19.2)	350 (24.6)	375 (26.4)	750 c/ (52.7 c/)
10	.26	128 (9.0)	200 (14.1)	469 c/ (33.0 c/)	613 c/ (43.1 c/)	—	—	—	—	—	85 (6.0)	193 (13.6)	305 (21.4)	333 (23.4)	667 c/ (46.9 c/)	750 c/ (52.7 c/)
11	.22	60 (4.2)	118 (8.3)	331 (23.3)	—	—	—	—	—	—	65 (4.6)	123 (8.6)	213 (15.0)	319 (22.4)	750 c/ (52.7 c/)	c/
12	.23	103 (7.2)	190 (13.4)	280 (19.7)	363 (25.5)	—	—	—	—	—	98 (6.9)	178 (12.5)	288 (20.2)	363 (25.5)	—	—
13	.23	105 (7.4)	195 (13.7)	310 (21.8)	438 (30.8)	534 (37.5)	650 c/ (45.7 c/)	750 c/ (52.7 c/)	c/	c/	73 (5.1)	135 (9.5)	266 (18.7)	342 (24.0)	375 (26.4)	—
14	.30	113 (7.9)	215 (15.1)	295 (20.7)	—	—	—	—	—	—	123 (8.6)	183 (12.9)	310 (21.8)	400 (28.1)	500 (35.2)	625 (43.9)
15	.26	85 (6.0)	285 (20.0)	425 (29.9)	600 c/ (42.2 c/)	675 c/ (47.5 c/)	750 c/ (52.7 c/)	c/	c/	c/	198 (13.9)	308 (21.7)	371 (26.1)	—	—	—
16	.32	20 (1.4)	78 (5.5)	216 (15.2)	381 (26.8)	538 c/ (37.8 c/)	700 c/ (49.2 c/)	750 c/ (52.7 c/)	c/	c/	33 (2.3)	95 (6.7)	188 (13.2)	397 (27.9)	525 (36.9)	683 c/ (48.0 c/)
17	.37	28 (2.0)	158 (11.1)	245 (17.2)	333 (23.4)	475 (33.4)	588 (41.3)	750 c/ (52.7 c/)	c/	c/	25 (1.8)	130 (9.1)	275 (19.3)	333 (23.4)	500 c/ (35.2 c/)	600 c/ (42.2 c/)
18	.37	38 (2.7)	155 (10.9)	330 (23.2)	525 (36.9)	750 c/ (52.7 c/)	c/	c/	c/	c/	28 (2.0)	110 (7.7)	245 (17.2)	450 (31.6)	588 (41.3)	688 c/ (48.4 c/)
19	.28	43 (3.0)	115 (8.1)	173 (12.2)	228 (16.0)	291 (20.5)	413 (29.0)	513 (36.1)	750 c/ (52.7 c/)	c/	45 (3.2)	120 (8.4)	[illegible] (13.6)	[illegible] (17.4)	363 (25.5)	[illegible]
20	.38	30 (2.1)	108 (7.6)	181 (12.7)	300 (21.1)	400 (28.1)	—	—	—	—	40 (2.8)	148 (10.4)	[illegible]	283 (19.9)	450 [illegible]	[illegible]
21	.33	11 (.8)	60 (4.2)	110 (7.7)	145 (10.2)	243 (17.1)	358 (25.2)	435 (30.6)	465 (32.[illegible])	485 (34.1)	30 [illegible]	55 (3.9)	88 (6.2)	145 [illegible]	[illegible]	[illegible]
22	.30	11 (.8)	48 (3.4)	95 (6.7)	113 (7.9)	225 (15.8)	365 (25.7)	475 (33.4)	503 (35.4)	513 (36.1)	11 [illegible]	45 [illegible]	95 (6.7)	118 [illegible]	[illegible] (14.8)	[illegible]

Indicated g, 15	18	24	Bottom of Crater 0	2	4	6	9	12	15	18	24	Moisture Content Percent Dry Weight Surface	Bottom of Crater	Density Wet 0-3 in (0-76 mm)	Dry 0-3 in (0-76 mm)
inches			inches												
381	457	610	0	51	102	152	229	305	381	457	610				
(millimeters)			(millimeters)												
meter)			pounds-per-square-inch (kilograms-per-square-centimeter)									%	%	lb/ft³ (kilograms/m³)	
—	—	—	138	252	478	650 c/	—	—	—	—	—	36.3	31.7	99.7	73.1
—	—	—	(9.7)	(17.7)	(33.6)	(45.7 c/)	—	—	—	—	—			(1597)	(1171)
750 c/	c/	c/	150	325	608 c/	—	—	—	—	—	—	41.5	31.6	100.8	71.2
(52.7 c/)	c/	c/	(10.5)	(22.8)	(42.7 c/)	—	—	—	—	—	—			(1615)	(1140)
—	—	—	195	495 c/	719 c/	—	—	—	—	—	—	45.6	27.0	98.0	67.3
—	—	—	(13.7)	(34.8 c/)	(50.6 c/)	—	—	—	—	—	—			(1570)	(1078)
c/	c/	c/	205	500 c/	—	—	—	—	—	—	—	36.5	27.0	96.6	70.8
c/	c/	c/	(14.4)	(35.2 c/)	—	—	—	—	—	—	—			(1547)	(1134)
750 c/	c/	c/	105	256	383	650 c/	750 c/	c/	c/	c/	c/	44.8	29.7	102.8	71.0
(52.7 c/)	c/	c/	(7.4)	(18.0)	(26.9)	(45.7 c/)	(52.7 c/)	c/	c/	c/	c/			(1647)	(1137)
750 c/	c/	c/	125	220	380	583 c/	617 c/	550 c/	750 c/	c/	c/	44.5	31.6	93.2	64.5
(52.7 c/)	c/	c/	(8.8)	(15.5)	(26.7)	(41.0 c/)	(43.4 c/)	(38.7 c/)	(52.7 c/)	c/	c/			(1493)	(1033)
600 c/	675 c/	750 c/	100	300	417	—	—	—	—	—	—	35.8	29.0	1[illegible]	76.4
(42.2 c/)	(47.5 c/)	(52.7 c/)		(7.0)	(21.1)	(29.3)	—	—	—	—	—	—		[illegible]	[illegible]24)
c/	c/	c/	78	160	285	523 c/	690 c/	700 c/	—	—	—	39.3	30.9	106.4	76.4
c/	c/	c/	(5.5)	(11.2)	(20.0)	(36.8 c/)	(48.5 c/)	(49.2 c/)	—	—	—			(1704)	(1224)
c/	c/	c/	125	345	383	—	—	—	—	—	—	42.2	30.3	97.6	68.6
c/	c/	c/	(8.8)	(24.3)	(26.9)	—	—	—	—	—	—			(1563)	(1099)
c/	c/	c/	155	417	750 c/	c/	c/	c/	c/	c/	c/	37.0	26.7	111.4	81.4
c/	c/	c/	(10.9)	(29.3)	(52.7 c/)	c/	c/	c/	c/	c/	c/			(1784)	(1304)
—	—	—	133	290	—	—	—	—	—	—	—	38.5	32.5	106.1	76.7
—	—	—	(9.4)	(20.4)	—	—	—	—	—	—	—			(1700)	(1229)
—	—	—	98	365	600	750 c/	c/	c/	c/	c/	c/	38.7	31.6	107.8	77.7
—	—	—	(6.9)	(25.7)	(42.2)	(52.7 c/)	c/	c/	c/	c/	c/			(1727)	(1245)
750 c/	c/	c/	138	233	350	425	488	—	—	—	—	43.1	28.0	104.6	73.1
(52.7 c/)	c/	c/	(9.7)	(16.4)	(24.6)	(29.9)	(34.3)	—	—	—	—			(1675)	(1171)
—	—	—	148	278	469	625 c/	675 c/	750 c/	c/	c/	c/	41.4	31.8	105.2	74.4
—	—	—	(10.4)	(19.5)	(33.0)	(43.9 c/)	(47.4 c/)	(52.7 c/)	c/	c/	c/			(1685)	(1192)
—	—	—	98	235	433	688 c/	750 c/	c/	c/	c/	c/	49.0	36.3	102.1	68.5
—	—	—	(6.9)	(16.5)	(30.4)	(48.4 c/)	(52.7 c/)	c/	c/	c/	c/			(1635)	(1097)
750 c/	c/	c/	145	355	—	—	—	—	—	—	—	38.4	29.2	110.4	79.8
(52.7 c/)	c/	c/	(10.2)	(25.0)	—	—	—	—	—	—	—			(1768)	(1278)
750 c/	c/	c/	128	295	—	—	—	—	—	—	—	48.3	28.3	103.8	70.0
(52.7 c/)	c/	c/	(9.0)	(20.7)	—	—	—	—	—	—	—			(1663)	[illegible]
750 c/	c/	c/	108	263	463	—	—	—	—	—	—	36.6	33.0	103.2	75.6
(52.7 c/)	c/	c/	(7.6)	(18.5)	(32.6)	—	—	—	—	—	—			(1653)	(1211)
—	—	—	53	178	394	613 c/	688 c/	750 c/	c/	c/	c/	44.3	60.9	98.8	68.5
—	—	—	(3.7)	(12.5)	(27.7)	(43.1 c/)	(48.4 c/)	(52.7 c/)	c/	c/	c/			(1583)	(1097)
420	460	493	33	83	100	148	175	195	220	235	268	8.4	8.2	110.0	101.4
(29.5)	(32.3)	(34.7)	(2.3)	(5.8)	(7.0)	(10.4)	(12.3)	(13.7)	(15.5)	(16.5)	(18.8)			(1762)	(1624)
445	483	490	58	110	113	155	188	198	225	233	260	5.3	7.0	98.9	94.0
(31.3)	(34.0)	(34.5)	(4.1)	(7.7)	(7.9)	(10.9)	(13.2)	(13.9)	(15.8)	(16.4)	(18.3)			(1584)	(1506)

Table B-2. Soils Data Analysis (cont)

Crater Number	Crater Depth (meters)	Ground surface before detonation: 0 in. (0 mm)	2 in. (51 mm)	4 in. (102 mm)	6 in. (152 mm)	9 in. (229 mm)	12 in. (305 mm)	15 in. (381 mm)	18 in. (457 mm)	24 in. (610 mm)	Crater Rim: 0 in. (0 mm)	2 in. (51 mm)	4 in. (102 mm)	6 in. (152 mm)	9 in. (229 mm)	12 in. (305 mm)
		Average Cone Index at Depth, pounds per square inch (kilograms per square centimeter)									pounds per square inch (kilograms per square centimeter)					
23	.44	13	63	127	170	165	133	113	113	130	15	50	123	163	138	[illegible]
		(.9)	(4.4)	(8.9)	(12.0)	(11.6)	(9.4)	(7.9)	(7.9)	(9.1)	(1.1)	(3.5)	(8.6)	(11.5)	(9.7)	(8.?)
24	.37	3	53	113	120	113	128	158	145	163	18	40	100	110	113	128
		(.2)	(3.7)	(7.9)	(8.4)	(7.9)	(9.0)	(11.1)	(10.2)	(11.5)	(1.3)	(2.8)	(7.0)	(7.7)	(7.9)	(9.0)
25	.24	8	46	78	123	240	290	453	460	475	10	38	73	120	123	268
		(.6)	(3.4)	(5.5)	(8.6)	(16.9)	(20.7)	(31.8)	(32.3)	(33.4)	(.7)	(2.7)	(5.1)	(8.4)	(8.7)	(18.8)
26	.29	17	55	85	118	198	280	320	330	350	13	53	83	118	190	240
		(1.2)	(3.9)	(6.0)	(8.3)	(13.9)	(19.7)	(22.5)	(23.2)	(24.6)	(.9)	(3.7)	(5.8)	(8.3)	(13.4)	(16.9)
27	.27	23	55	80	170	360 c	540 c	610 c	640 c	675 c	10	25	6?	148	235	340
		(1.6)	(3.9)	(5.6)	(12.0)	(25.3 c)	(38.0 c)	(42.9 c)	(45.0 c)	(47.5 c)	(.7)	(1.8)	(4.?)	(10)	(16.5)	(23.9)
28	.37	13	58	130	150	140	123	125	210	255	15	58	120	153	140	148
		(.9)	(4.1)	(9.1)	(10.5)	(9.8)	(8.6)	(8.8)	(14.8)	(17.9)	(1.1)	(4.1)	(8.4)	(10.8)	(9.8)	(10.4)
29	.36	13	53	120	153	148	145	125	178	235	11	35	98	155	153	165
		(.9)	(3.7)	(8.4)	(10.8)	(10.4)	(10.2)	(8.8)	(12.5)	(16.5)	(.8)	(2.5)	(6.9)	(10.9)	(10.8)	(11.6)
30	.39	20	50	95	173	320	445	545 c	590 c	710 c	13	40	78	158	253	355
		(1.4)	(3.5)	(6.7)	(12.2)	(22.5)	(31.3)	(38.3 c)	(41.5 c)	(49.9 c)	(.9)	(2.8)	(5.5)	(11.1)	(17.8)	(25.0)
31	.42	30	65	85	160	190	243	360 c	373 c	390 c	13	40	88	145	183	250
		(2.1)	(4.6)	(6.0)	(11.2)	(13.4)	(17.1)	(25.3 c)	(26.2 c)	(27.4 c)	(.9)	(2.8)	(6.2)	(10.2)	(12.9)	(17.6)
32	.29	38	105	145	220	375	430	690 c	750 c	c/	25	60	143	243	350	440
		(2.7)	(7.4)	(10.2)	(15.5)	(26.4)	(30.2)	(48.5 c)	(52.7 c)	c	(1.8)	(4.2)	(10.1)	(17.1)	(24.6)	(30.9)
33	.22	85	160	228	400	—	—	—	—	—	60	145	205	303	338	550 c
		(6.0)	(11.2)	(16.0)	(28.1)	—	—	—	—	—	(4.2)	(10.2)	(14.4)	(21.3)	(23.8)	(38.7 c)
34	.23	80	220	367	467	400	—	—	—	—	55	145	203	344	375	—
		(5.6)	(15.5)	(25.8)	(32.8)	(28.1)	—	—	—	—	(3.9)	(10.2)	(14.3)	(24.2)	(26.4)	—
35	.22	73	163	238	478	700 c	750 c	c	c	c/	80	168	281	463	—	—
		(5.1)	(11.5)	(16.7)	(33.6)	(49.2 c)	(52.7 c)	c	c	c	(5.6)	(11.8)	(19.8)	(32.6)	—	—
36	.23	123	275	375	—	—	—	—	—	—	110	238	306	513	—	—
		(8.6)	(19.3)	(26.4)	—	—	—	—	—	—	(7.7)	(16.7)	(21.5)	(36.1)	—	—
37	.31	98	215	354	—	—	—	—	—	—	100	143	190	—	—	—
		(6.9)	(15.1)	(24.9)	—	—	—	—	—	—	(7.0)	(10.1)	(13.4)	—	—	—
38	.30	70	173	233	425	600 c	613 c	625 c	—	—	58	123	241	—	—	—
		(4.9)	(12.2)	(16.4)	(29.9)	(42.2 c)	(43.1 c)	(43.9 c)	—	—	(4.1)	(8.6)	(16.9)	—	—	—
39	.21	118	223	298	438	525	617	750 c	c	c	175	238	370	550	700 c	750 c
		(8.3)	(15.7)	(21.0)	(30.8)	(36.9)	(43.4)	(52.7 c)	c	c	(12.3)	(16.7)	(26.0)	(38.7)	(49.2 c)	(52.7 c)
40	.23	105	230	300	425	569 c	650 c	750 c	c	c	68	155	273	385	350	444
		(7.4)	(16.2)	(21.1)	(29.9)	(40.0 c)	(45.7 c)	(52.7 c)	c	c	(4.8)	(10.9)	(19.2)	(27.1)	(24.6)	(31.2)
41	.21	123	210	230	328	373	—	—	—	—	55	123	188	267	306	413
		(8.6)	(14.8)	(16.2)	(23.1)	(26.1)	—	—		—	(3.9)	(8.6)	(13.2)	(18.8)	(21.5)	(29.0)
42	.30	105	213	285	413	500		—	—	—	113	173	245	304	444	675
		(7.4)	(15.0)	(20.0)	(29.0)	(35.2)		—	—	—	(7.9)	(12.2)	(17.2)	(21.4)	(31.2)	(47.5)
43	.32	93	225	350	600 c	—			—		95	235	255	419	506	613 c
		(6.5)	(15.8)	(24.6)	(42.2 c)				—	—	(6.7)	(16.5)	(17.9)	(29.5)	(35.6)	(43.1 c)
44	.35	118	240	310	575 c	750 c	c			c	63	190	228	317	375	483
		(8.3)	(16.9)	(21.8)	(40.4 c)	(52.7 c)	c	c	c	c	(4.4)	(13.4)	(16.0)	(22.3)	(26.4)	(34.0)

Indicated a/

meter)

15 in (381 mm)	18 in (457 mm)	24 in (610 mm)	Bottom of Crater 0 in (0 mm)	2 in (51 mm)	4 in (102 mm)	6 in (152 mm)	9 in (229 mm)	12 in (305 mm)	15 in (381 mm)	18 in (457 mm)	24 in (610 mm)	Moisture Content Percent Dry Weight: Surface %	Moisture Content Percent Dry Weight: Bottom of Crater %	Density Wet 0-3 in (0-76 mm) lb/ft³ (kilograms/m³)	Density Dry 0-3 in (0-76 mm) lb/ft³ (kilograms/m³)
inches (millimeters)			pounds-per-square-inch (kilograms-per-square-centimeter)												
108 (7.6)	110 (7.7)	123 (8.6)	43 (3.0)	68 (4.8)	85 (6.0)	100 (7.0)	110 (7.7)	110 (7.7)	120 (8.4)	128 (9.0)	145 (10.2)	5.4	7.9	161.4 (2585)	153.0 (2451)
150 (10.5)	153 (10.8)	170 (12.0)	23 (1.6)	55 (3.9)	75 (5.3)	103 (7.2)	105 (7.4)	108 (7.6)	120 (8.4)	130 (9.1)	140 (9.8)	4.4	5.2	141.3 (2263)	135.3 (2167)
420 (29.5)	445 (31.3)	483 (34.0)	43 (3.0)	88 (6.2)	118 (8.3)	185 (13.0)	215 (15.1)	245 (17.2)	248 (17.4)	253 (17.8)	263 (18.5)	3.5	8.3	97.6 (1563)	94.3 (1511)
300 (21.1)	330 (23.2)	345 (24.2)	30 (2.1)	78 (5.5)	113 (7.9)	185 (13.0)	220 (15.5)	230 (16.2)	250 (17.6)	248 (17.4)	253 (17.8)	5.0	5.6	101.3 (1623)	96.4 (1544)
405 (28.5)	490 (34.5)	575 (40.4)	15 (1.1)	45 (3.2)	153 (10.8)	213 (15.0)	203 (14.3)	210 (14.8)	213 (15.0)	225 (15.8)	238 (16.7)	11.5	7.6	98.6 (1579)	88.5 (1418)
130 (9.1)	198 (13.9)	255 (17.9)	15 (1.1)	43 (3.0)	70 (4.9)	103 (7.2)	160 (11.2)	233 (16.4)	300 (21.1)	325 (22.8)	373 (26.2)	15.1	21.4	110.4 (1768)	95.9 (1536)
143 (10.1)	173 (12.2)	235 (16.5)	11 (.8)	28 (2.0)	58 (4.1)	110 (7.7)	158 (11.1)	220 (15.5)	265 (18.6)	290 (20.4)	343 (24.1)	7.0	6.1	94.1 (1507)	87.9 (1408)
430 (30.2)	518 (36.4)	615 (43.2)	23 (1.6)	55 (3.9)	155 (10.9)	170 (12.0)	198 (13.9)	195 (13.7)	213 (15.0)	220 (15.5)	235 (16.5)	15.6	16.5	103.5 (1658)	89.5 (1434)
325 (22.8)	370 (26.0)	415 c/ (29.2 c/)	30 (2.1)	83 (5.8)	95 (6.7)	98 (6.9)	108 (7.6)	113 (7.9)	120 (8.4)	128 (9.0)	143 (10.1)	21.6	20.7	102.1 (1635)	84.0 (1346)
580 (40.8)	700 c/ (49.2 c/)	730 c/ (51.3 c/)	20 (1.4)	70 (4.9)	113 (7.9)	128 (9.0)	145 (10.2)	175 (12.3)	193 (13.6)	230 (16.2)	265 (18.6)	12.6	10.0	94.6 (1515)	84.0 (1346)
750 c/ (52.7 c/)	c/ c/	c/ c/	78 (5.5)	195 (13.7)	313 (22.0)	488 (34.3)	538 (37.8)	625 (43.9)	750 c/ (52.7 c/)	c/ c/	c/ c/	48.8	31.7	86.2 (1381)	57.9 (927)
— —	— —	— —	88 (6.2)	265 (18.6)	363 (25.5)	519 (36.5)	675 c/ (47.5 c/)	— —	— —	— —	— —	40.8	31.5	97.9 (1568)	69.5 (1113)
— —	— —	— —	110 (7.7)	365 (25.7)	500 (35.2)	625 (43.9)	688 c/ (48.4 c/)	— —	— —	— —	— —	43.1	31.8	91.4 (1464)	63.8 (1022)
— —	— —	—	130 (9.1)	290 (20.4)	447 (31.4)	625 (43.9)	750 c/ (52.7 c/)	c/ c/	c/ c/	c/ c/	c/ c/	27.4	29.1	94.6 (1515)	74.2 (1189)
— —	— —	— —	98 (6.9)	255 (17.9)	369 (25.9)	544 (38.2)	725 c/ (51.0 c/)	750 c/ (52.7 c/)	c/ c/	c/ c/	c/ c/	31.9	23.8	101.7 (1629)	77.1 (1235)
— —	— —	— —	80 (5.6)	215 (15.1)	295 (20.7)	438 (30.8)	— —	— —	— —	— —	— —	41.6	34.5	94.4 (1512)	66.7 (1068)
c/ c/	c/ c/	c/ c/	140 (9.8)	275 (19.3)	485 c/ (34.1 c/)	548 c/ (38.5 c/)	588 c/ (41.3 c/)	683 c/ (48.0 c/)	— —	— —	— —	32.1	37.4	110.5 (1770)	83.6 (1339)
— —	— —	— —	103 (7.2)	288 (20.2)	403 (28.3)	625 (43.9)	713 c/ (50.1 c/)	750 c/ (52.7 c/)	c/ c/	c/ c/	c/ c/	37.8	33.1	105.2 (1685)	76.3 (1222)
463 (32.6)	— —	— —	68 (4.8)	218 (15.3)	313 (22.0)	750 c/ (52.7 c/)	c/ c/	c/ c/	c/ c/	c/ c/	c/ c/	26.5	34.8	82.7 (1325)	65.4 (1048)
713 c/ (50.1 c/)	— —	— —	95 (6.7)	350 (24.6)	575 (40.4)	713 c/ (50.1 c/)	— —	— —	— —	— —	— —	34.1	27.5	76.3 (1222)	56.9 (911)
— —	— —	— —	198 (13.9)	395 (27.8)	492 (34.6)	750 c/ (52.7 c/)	c/ c/	c/ c/	c/ c/	c/ c/	c/ c/	30.7	30.5	96.2 (1541)	73.6 (1179)
750 c/ (52.7 c/)	c/ c/	c/ c/	145 (10.2)	295 (20.7)	435 (30.6)	640 c/ (45.0 c/)	750 c/ (52.7 c/)	c/ c/	c/ c/	c/ c/	c/ c/	30.8	24.6	97.7 (1565)	74.7 (1197)

Table B-2. Soils Analysis Data (concluded)

Average Cone Index at Depth — Crater Rim — inches (millimeters) — pounds per square inch (kilograms per square centimeter)

Crater Number	Depth (meters)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1 (25)	2 (51)	4 (102)	6 (152)	9 (229)	12 (305)
45	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]				188	[illegible]	268	[illegible]	408	[illegible]
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]				(13.2)	(19.2)	(18.8)	[illegible]	(28.7)	(36.1)
46	[illegible]	168	[illegible]	[illegible]	44[illegible]	468		[illegible]	[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	420	458 c/
		(11.8)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			(9.1)	[illegible]	[illegible]	[illegible]	(29.5)	(32.2 c/)
47	[illegible]	98	[illegible]	[illegible]	[illegible]	[illegible]						108	[illegible]	[illegible]	[illegible]	400	[illegible]
		(6.9)	[illegible]	[illegible]	[illegible]	[illegible]						[illegible]	[illegible]	[illegible]	[illegible]	(28.1)	(38.7)
48	.26	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	442	608 c/
		(10.1)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	48.4	[illegible]	[illegible]		(7.4)	(14.4)	(17.9)	(22.1)	(31.1)	(42.7 c/)
49	.32	62	150	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	259	[illegible]	331	[illegible]
		(4.4)	(10.5)	[illegible]	[illegible]	[illegible]	(26.2)	(31.6)	(34.6)			(4.2)	(11.2)	(18.2)	(20.5)	(23.3)	(26.2)
50	.43	80	205	298	[illegible]	[illegible]	608 c/	658 c/	[illegible]			68	[illegible]	208	300	355	414
		(5.6)	(14.4)	[illegible]	[illegible]	(40.4 c/)	(42.7 c/)	(46.3 c/)	(50.4 c/)			(4.8)	(10.9)	[illegible]	[illegible]	(25.0)	(29.8)
51	.39	68	130	[illegible]	383	[illegible]	663 c/	750 c/	c/			65	205	250	363	383	479
		(4.8)	(9.1)	[illegible]	(26.9)	(37.5)	(46.6 c/)	(52.7 c/)		c/		(4.6)	(14.4)	(17.6)	(25.5)	(26.9)	(33.7)
52	.35	58	140	325	[illegible]	425						65	143	285	345	417	425
		(4.1)	(9.8)	(22.8)	(21.4)	(29.9)						(4.6)	(9.8)	(20.0)	(24.3)	(29.3)	(29.9)
53	.30	70	120	221	[illegible]	288	360	283	292	317		48	108	215	265	283	303
		(4.9)	(8.4)	(15.5)	(19.0)	(20.2)	(25.3)	(19.9)	(20.5)	(22.3)		(3.4)	(7.6)	(15.1)	(18.6)	(19.9)	(21.3)
54	.24	80	163	369	513	—	--		--	--		53	185	370	558	658 c/	750 c/
		(5.6)	(11.5)	(25.9)	(36.1)	--	--		--	--		(3.7)	(13.0)	(26.0)	(39.2)	(46.3 c/)	(52.7 c/)
55	.23	55	135	223	233	275	300	283	317	350		58	180	230	263	310	340
		(3.9)	(9.5)	(15.7)	(16.4)	(19.3)	(21.1)	(19.9)	(22.3)	(24.6)		(4.1)	(12.7)	(16.2)	(18.5)	(21.8)	(23.9)
56	.28	58	165	305	300	375	433	517	—	--		73	158	285	334	392	450
		(4.1)	(11.6)	(21.4)	(21.1)	(26.4)	(30.4)	(36.3)	—	--		(5.1)	(11.1)	(20.0)	(23.5)	(27.6)	(31.6)
57	.54	45	98	150	250	340 c/	650 c/	655 c/	665 c/	685 c/		[illegible]	52	50	97	245	510 c/
		(3.2)	(6.9)	(10.5)	(17.6)	(23.9 c/)	(45.7 c/)	(46.1 c/)	(46.8 c/)	(48.2 c/)		(1.8)	(3.4)	(3.5)	(6.8)	(17.2)	(35.9 c/)
58	.38	75	122	145	192	240	490	530 c/	575 c/	665 c/		[illegible]	[illegible]	115	160	192	203
		(5.3)	(8.6)	(10.2)	(13.5)	(16.9)	(34.5)	(37.3 c/)	(40.4 c/)	(46.8 c/)		(2.2)	(4.1)	(8.1)	(11.2)	(13.5)	(14.3)
59	.43	65	85	125	150	230	380 c/	535 c/	750 c/	c/		18	45	60	[illegible]	130	210
		(4.6)	(6.0)	(8.8)	(12.0)	(16.2)	(26.7 c/)	(37.6 c/)	(52.7 c/)	c/		(1.3)	(3.2)	[illegible]	(5.3)	(9.1)	(14.8)
60	.45	52	105	150	315 c/	385 c/	570 c/	750 c/	c/	c/		25	58	80	90	135	180
		(3.7)	(7.4)	(10.5)	(22.1 c/)	(27.1 c/)	(40.1 c/)	(52.7 c/)	c/	c/		(1.8)	(4.1)	(5.6)	(6.3)	(9.5)	(12.7)
61	.25	50	102	178	250 c/	275 c/	318 c/	348 c/	350 c/	375 c/		45	90	100	125	295 c/	358 c/
		(3.5)	(7.2)	(12.5)	(17.6 c/)	(19.3 c/)	(22.4 c/)	(24.5 c/)	(24.6 c/)	(26.4 c/)		(3.2)	(6.3)	(7.0)	(8.8)	(20.7 c/)	(25.2 c/)
62	.29	65	90	140	185	220	265	265	485 c/	680 c/		28	70	135	120	130	160
		(4.6)	(6.3)	(9.8)	(13.0)	(15.5)	(18.6)	(18.6)	(34.1 c/)	(47.8 c/)		(2.0)	(4.9)	(9.5)	(8.4)	(9.1)	(11.2)
63	.41	55	100	140	[illegible]	272	185	188	192	472 c/		48	80	90	112	145	148
		(3.9)	(7.0)	(9.8)	[illegible]	(19.1)	(13.0)	(13.2)	(13.5)	(33.2 c/)		(3.4)	(5.6)	(6.3)	(7.9)	(10.2)	(10.4)
64	.58	70	100	[illegible]	208	235	235	260	320	515 c/		35	80	92	100	132.5	140
		(4.9)	(7.0)	(10.0)	(14.6)	(16.5)	(16.5)	(18.3)	(22.5)	(36.2 c/)		(2.5)	(5.6)	(6.5)	(7.0)	(9.4)	(9.8)
65	.40	65	98	120	218	228	285	250	340	438 c/		30	50	88	[illegible]	128	180
		(4.6)	(6.9)	(8.4)	(15.3)	(16.0)	(20.0)	(17.6)	(23.9)	(30.8 c/)		(2.1)	(3.5)	(6.2)	(6.3)	(9.0)	(12.7)
66	.45	85	105	138	230	445 c/	490 c/	600 c/	700 c/	750 c/		[illegible]	45	85	115	118	160
		(6.0)	(7.4)	(9.7)	(16.2)	(31.3 c/)	(34.5 c/)	(42.2 c/)	(49.2 c/)	(52.7 c/)		(1.3)	(3.2)	(6.0)	(8.1)	(8.3)	(11.2)

a/ The mean CI values are an average of [illegible] readings taken at each crater site. c/ Denotes maximum depth measured because of [illegible] rocks with

Indicated a/

meter)

15 in (381 mm)	18 in (457 mm)	24 in (610 mm)	Bottom of Crater 0 in (0 mm)	2 in (51 mm)	4 in (102 mm)	6 in (152 mm)	9 in (229 mm)	12 in (305 mm)	15 in (381 mm)	18 in (457 mm)	24 in (610 mm)	Moisture Content Percent Dry Weight Surface %	Bottom of Crater %	Density Wet 0-3 in (0-76 mm) lb/ft³ (kilograms/m³)	Dry 0-3 in (0-76 mm)
			pounds-per-square-inch (kilograms-per-square-centimeter)												
750 c/	c/	c/	138	308	420	692 c/	750 c/	c/	c/	c/	c/	26.5	26.6	101.0	79.9
(52.7 c/)	c/	c/	(9.7)	(21.7)	(29.5)	(48.7 c/)	(52.7 c/)	c/	c/	c/	c/			(1618)	(1280)
463 c/	—	—	98	168	325	413	508	550	750 c/	c/	c/	36.3	36.3	101.6	74.5
(32.6 c/)	—	—	(6.9)	(11.8)	(22.8)	(29.0)	(35.7)	(38.7)	(52.7 c/)	c/	c/			(1627)	(1193)
—	—	—	95	295	475	600 c/	—	—	—	—	—	38.5	29.7	104.7	75.6
—	—	—	(6.7)	(20.7)	(33.4)	(42.2 c/)	—	—	—	—	—			(1677)	(1211)
700 c/	750 c/	c/	135	330	663 c/	700 c/	725 c/	750 c/	c/	c/	c/	29.1	29.8	97.4	75.5
(49.2 c/)	(52.7 c/)	c/	(9.5)	(23.2)	(46.6 c/)	(49.2 c/)	(51.0 c/)	(52.7 c/)	c/	c/	c/			(1560)	(1209)
419	463	531 c/	83	233	390	588 c/	717 c/	—	—	—	—	38.8	33.2	104.1	75.0
(29.5)	(32.6)	(37.3 c/)	(5.8)	(16.4)	(27.4)	(41.3 c/)	(50.4 c/)	—	—	—	—			(1667)	(1201)
538	650 c/	750 c/	115	250	319	428	513	533	617 c/	750 c/	c/	33.0	32.5	93.8	70.5
(37.8)	(45.7 c/)	(52.7 c/)	(8.1)	(17.6)	(22.4)	(30.1)	(36.1)	(37.5)	(43.4 c/)	(52.7 c/)	c/			(1502)	(1129)
581	688 c/	750 c/	140	305	450	700 c/	750 c/	c/	c/	c/	c/	44.0	30.7	93.0	64.6
(40.8)	(48.4 c/)	(52.7 c/)	(9.8)	(21.4)	(31.6)	(49.2 c/)	(52.7 c/)	c/	c/	c/	c/			(1490)	(1035)
—	—	—	115	253	340	500	580 c/	713 c/	750 c/	c/	c/	44.6	29.5	89.1	61.6
—	—	—	(8.1)	(17.8)	(23.9)	(35.2)	(40.8 c/)	(50.1 c/)	(52.7 c/)	c/	c/			(1427)	(987)
305	330	340	60	125	180	230	267	288	331	381	406	41.2	29.2	72.5	51.3
(21.4)	(23.2)	(23.9)	(4.2)	(8.8)	(12.7)	(16.2)	(18.8)	(20.2)	(23.3)	(26.8)	(28.5)			(1161)	(822)
c/	c/	c/	118	315	395	450	488	519	575	700 c/	750 c/	31.9	24.0	97.5	73.8
c/	c/	c/	(8.3)	(22.7)	(27.8)	(31.6)	(34.3)	(36.5)	(40.4)	(49.2 c/)	(52.7 c/)			(1562)	(1182)
[illegible]	331	344	58	108	168	218	250	233	246	292	321	44.4	32.6	96.3	66.7
(22.8)	(23.3)	(24.2)	(4.1)	(7.6)	(11.8)	(15.3)	(17.6)	(16.4)	(17.3)	(20.5)	(22.6)			(1543)	(1068)
—	—	—	58	243	330	525	575	—	—	—	—	28.0	27.2	92.6	72.4
—	—	—	(4.1)	(17.1)	(23.2)	(36.9)	(40.4)	—	—	—	—			(1483)	(1160)
550 c/	590 c/	640 c/	12	17	15	60	360 c/	681 c/	694 c/	725 c/	750 c/	65.4	57.9	88.5	53.5
(38.7 c/)	(41.5 c/)	(45.0 c/)	(.8)	(1.2)	(1.1)	(4.2)	(25.3 c/)	(47.9 c/)	(48.8 c/)	(51.0 c/)	(52.7 c/)			(1418)	(8[illegible]7)
285	340	375	25	42	[illegible]	95	115	172	212	220	280	66.9	60.1	93.0	55.7
(20.0)	(23.9)	(26.4)	(1.8)	(3.0)	(4.0)	(6.7)	(8.1)	(12.1)	(14.9)	(15.5)	(19.7)			(1490)	(892)
255	298	345	28	65	65	82	145	515 c/	540 c/	750 c/	c/	71.6	59.2	89.3	52.0
(17.9)	(21.0)	(24.3)	(2.0)	(4.6)	(4.6)	(5.8)	(10.2)	(36.2 c/)	(38.0 c/)	(52.7 c/)	c/			(1430)	(833)
290	315	378	50	590 c/	—	—	—	—	—	—		62.7	52.7	90.5	55.6
(20.4)	(22.1)	(26.6)	(3.5)	(41.5 c/)	—	—	—	—	—	—	—			(1450)	(891)
375 c/	382 c/	600 c/	[illegible]	58	98	[illegible]	200	240	180	195	470 c/	71.7	71.0	98.2	57.2
(26.4 c/)	(19.8 c/)	(42.2 c/)	(2.2)	(4.1)	(6.9)	(8.1)	(14.1)	(16.9)	(12.7)	(13.7)	(33.0 c/)			(1573)	(916)
160	195	360 c/	48	82	75	98	128	[illegible]	225	310	380	79.8	60.2	88.6	49.3
(11.2)	(13.7)	(25.3 c/)	(3.4)	(5.8)	(5.3)	(6.9)	(9.0)	(9.5)	(15.8)	(21.8)	(26.[illegible])			(1419)	(790)
155	208	235	52	82	90	98	108	108	98	108	210	75.5	72.9	89.4	51.0
(10.9)	(14.6)	(16.5)	(3.7)	(5.8)	(6.3)	(6.9)	(7.6)	(7.6)	(6.9)	(7.6)	(14.8)			(143[illegible])	(81[illegible])
180	180	355 c/	20	40	48	[illegible]	98	260	390	435	[illegible]	[illegible]	60.3	91.1	52.6
(12.7)	(12.7)	(25.0 c/)	(1.4)	(2.8)	(3.4)	(5.[illegible])	(6.9)	(18.[illegible])	(27.4)	(30.6)	(46.[illegible])			(1459)	(843)
285	250	300	48	[illegible]	62	80	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	90.0	54.1
(20.0)	(17.6)	(21.1)	(3.4)	(3.9)	(4.4)	[illegible]	[illegible]	[illegible]	(46.[illegible])	(49.[illegible])	[illegible]			(1442)	(867)
325	370	445	18	28	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	90.9	52.6
(22.8)	(26.0)	(31.3)	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]		[illegible]	(4[illegible])			(1456)	(843)

instrument. c/ CI greater than 750 [illegible]

TABLE B-3. SOIL DESCRIPTION

Crater Number	Soil Layer in (mm)	Mechanical Analysis Gravel %	Sand %	Silt %	Clay %	Unified Soil Classification System Classification	Fines %	Organic Matter %	Atterburg Limits LL %	PL %	PI %
1	0 to 6 (0 to 152)	13	14	63	10	MH	73	0.85	56	40	16
	12 to 18 (305 to 457)	6	26	47	21	MH	68	1.50	51	36	15
2	0 to 6 (0 to 152)	12	20	56	12	MH	68	0.26	51	39	12
	12 to 18 (305 to 457)	12	21	54	13	MH	67	1.54	52	44	8
3	0 to 6 (0 to 152)	4	29	51	16	MH	67	0.32	60	36	24
	6 to 12 (152 to 305)	2	29	52	17	MH	69	1.00	59	37	22
4	0 to 6 (0 to 152)	5	27	47	21	MH	68	1.73	56	42	14
	12 to 18 (305 to 457)	9	20	54	17	ML	71	1.29	43	32	11
6	0 to 6 (0 to 152)	7	22	54	17	MH	71	2.39	59	46	13
	6 to 12 (152 to 305)	2	25	56	17	ML	73	0.26	46	33	13
7	0 to 6 (0 to 152)	3	22	61	14	MH	75	0.29	56	41	15
	6 to 12 (152 to 305)	1	24	63	12	MH	75	0.89	55	43	12
8	0 to 6 (0 to 152)	12	22	46	20	ML	66	0.69	48	38	10
	6 to 12 (152 to 305)	12	8	6	74	CH	80	0.27	52	31	21
9	0 to 6 (0 to 152)	5	28	43	24	OH	67	13.62	61	34	27
	6 to 12 (152 to 305)	3	26	51	20	MH	71	0.14	57	38	19
10	0 to 6 (0 to 152)	12	20	54	14	OH	68	1.39	62	40	22
	6 to 12 (152 to 305)	4	29	31	36	CL	67	0.03	48	23	25
11	0 to 6 (0 to 152)	3	28	52	17	MH	69	1.53	52	44	8
	6 to 12 (152 to 305)	11	23	54	12	ML	66	1.00	43	29	14
12	0 to 6 (0 to 152)	1	24	57	18	MH	75	0.36	58	49	9
	6 to 12 (152 to 305)	5	24	25	46	CL	71	1.44	48	30	18
13	0 to 6 (0 to 152)	2	26	57	15	MH	72	0.28	63	45	18
	6 to 12 (152 to 305)	5	27	53	15	MH	68	2.10	53	42	11
14	0 to 6 (0 to 152)	3	22	57	18	MH	75	1.29	59	35	24
	12 to 18 (305 to 457)	12	12	61	15	ML	76	0.06	47	30	17
15	0 to 6 (0 to 152)	7	17	40	36	OH	76	16.37	62	38	24
	6 to 12 (152 to 305)	3	26	51	20	MH	71	0.58	58	36	22
16	0 to 6 (0 to 152)	4	29	51	16	MH	67	0.32	60	36	24
	6 to 12 (152 to 305)	12	19	52	17	MH	69	1.00	59	37	22

Table B-3. Soil Description (cont)

Crater Number	Soil Layer in (mm)	Mechanical Analysis Gravel %	Sand %	Silt %	Clay %	Unified Soil Classification System Classification	Fines %	Organic Matter %	Atterburg Limits LL %	PL %	PI %
17	0 to 6 (0 to 152)	2	23	57	18	MH	75	0.47	51	32	19
	12 to 18 (305 to 457)	8	22	54	16	MH	70	0.99	55	34	21
18	0 to 6 (0 to 152)	1	27	56	16	MH	72	1.00	58	48	10
	12 to 18 (305 to 457)	13	10	10	67	CL	77	1.87	47	20	27
19	0 to 6 (0 to 152)	1	27	56	1'	MH	72	1.00	58	48	10
	12 to 18 (305 to 457)	13	10	10	67	CL	77	1.87	48	20	28
20	0 to 6 (0 to 152)	12	18	6	64	CL	70	0.54	45	20	25
	12 to 18 (305 to 457)	8	17	29	46	OH	75	10.63	70	46	24
21	0 to 6 (0 to 152)	2	86	12	0	SW	12	0.00	—	—	—
	12 to 18 (305 to 457)	0	99	1	0	SW	1	0.00	—	—	—
22	0 to 6 (0 to 152)	2	86	12	0	SW	12	0.00	—	—	—
	12 to 18 (305 to 457)	0	99	1	0	SW	1	0.00	—	—	—
23	0 to 6 (0 to 152)	1	96	3	0	SW	3	0.00	—	—	—
	12 to 18 (305 to 457)	0	98	2	0	SW	2	0.00	—	—	—
24	0 to 6 (0 to 152)	1	96	3	0	SW	3	0.00	—	—	—
	12 to 18 (305 to 457)	0	98	2	0	SW	2	0.00	—	—	—
25	0 to 6 (0 to 152)	1	94	5	0	SW	5	0.00	—	—	—
	6 to 12 (152 to 305)	0	97	3	0	SW	3	0.00	—	—	—
26	0 to 6 (0 to 152)	1	94	5	0	SW	5	0.00	—	—	—
	12 to 18 (305 to 457)	0	97	3	0	SW	3	0.00	—	—	—
27	0 to 6 (0 to 152)	1	93	6	0	SW	6	0.00	—	—	—
	12 to 18 (305 to 457)	2	76	14	8	SW	22	3.41	—	—	—
28	0 to 6 (0 to 152)	0	89	11	0	SW	11	0.00	—	—	—
	12 to 18 (305 to 457)	0	93	7	0	SW	7	0.06	—	—	
29	0 to 6 (0 to 152)	0	89	11	0	SW	11	0.00	—	—	—
	12 to 18 (305 to 457)	0	93	7	0	SW	7	0.06	—	—	—
30	0 to 6 (0 to 152)	1	93	6	0	SW	6	0.00	—	—	—
	12 to 18 (305 to 457)	2	76	14	8	SW	22	3.41	—	—	—
31	0 to 6 (0 to 152)	0	99	1	0	SW	1	0.00	—	—	—
	12 to 18 (305 to 457)	0	96	4	0	SW	4	0.00	—	—	—

Table B-3. Soil Description (cont)

Crater Number	Soil Layer in (mm)	Mechanical Analysis Gravel %	Sand %	Silt %	Clay %	Unified Soil Classification System Classification	Fines %	Organic Matter %	Atterburg Limits LL %	PL %	PI %
32	0 to 6 (0 to 152)	0	99	1	0	SW	1	0.00	--	--	--
	12 to 18 (305 to 457)	0	96	4	0	SW	4	0.00	--	--	--
33	0 to 6 (0 to 152)	10	14	66	10	MH	76	0.76	57	46	11
	6 to 12 (152 to 305)	10	2	17	71	CH	88	2.41	61	18	43
34	0 to 6 (0 to 152)	11	18	50	21	MH	71	2.34	61	56	5
	6 to 12 (152 to 305)	5	27	51	17	ML	68	1.45	45	35	10
35	0 to 6 (0 to 152)	11	18	50	21	MH	71	2.34	62	56	6
	6 to 12 (152 to 305)	5	27	51	17	ML	68	1.45	45	35	10
36	0 to 6 (0 to 152)	1	26	52	21	MH	73	0.02	53	36	17
	6 to 12 (152 to 305)	3	21	60	16	MH	76	1.97	53	42	11
37	0 to 6 (0 to 152)	11	16	62	11	MH	73	0.02	53	36	17
	6 to 12 (152 to 305)	3	21	60	16	MH	76	1.97	53	42	11
38	0 to 6 (0 to 152)	2	27	54	17	MH	71	0.00	56	36	20
	12 to 18 (305 to 457)	10	24	52	14	MH	66	0.00	54	40	14
39	0 to 6 (0 to 152)	12	18	57	13	ML	70	4.14	45	37	8
	6 to 12 (152 to 305)	10	16	59	15	MH	74	0.36	55	39	16
40	0 to 6 (0 to 152)	13	14	53	20	MH	73	0.85	56	40	16
	6 to 12 (152 to 305)	6	26	47	21	MH	68	1.50	51	36	15
41	0 to 6 (0 to 152)	2	28	57	13	OL	70	4.14	42	33	9
	6 to 12 (152 to 305)	10	23	49	18	ML	67	0.00	42	13	29
42	0 to 6 (0 to 152)	12	20	54	14	OH	68	1.39	63	40	23
	12 to 18 (305 to 457)	14	19	31	36	CL	67	0.03	47	23	24
43	0 to 6 (0 to 152)	1	19	4	76	CH	80	3.32	68	25	43
	12 to 18 (305 to 457)	10	16	52	22	ML	74	1.57	46	33	13
44	0 to 6 (0 to 152)	1	19	4	76	CH	80	3.32	68	25	43
	12 to 18 (305 to 457)	5	21	62	12	ML	74	1.57	46	33	13
45	0 to 6 (0 to 152)	12	18	57	13	ML	70	4.14	45	37	8
	12 to 18 (305 to 457)	10	16	59	15	MH	74	0.36	55	39	16
46	0 to 6 (0 to 152)	10	18	56	16	MH	72	1.32	53	35	18
	12 to 18 (305 to 457)	11	17	59	13	MH	72	1.97	54	36	18

Table B-3. Soil Description (cont)

Crater Number	Soil Layer in (mm)	Mechanical Analysis Gravel %	Sand %	Silt %	Clay %	Unified Soil Classification System Classification	Fines %	Organic Matter %	Atterburg Limits LL %	PL %	PI %
47	0 to 6 (0 to 152)	12	15	57	16	MH	73	0.41	55	41	14
	12 to 18 (305 to 457)	13	11	30	46	CL	76	2.04	43	14	29
48	0 to 6 (0 to 152)	12	15	57	16	MH	73	0.41	55	41	14
	6 to 12 (152 to 305)	13	11	30	46	CL	76	2.04	43	14	29
49	0 to 6 (0 to 152)	5	22	53	20	MH	73	0.86	56	41	15
	12 to 18 (305 to 457)	10	18	51	21	MH	72	0.00	55	40	15
50	0 to 6 (0 to 152)	11	22	50	17	ML	67	2.21	42	29	13
	12 to 18 (305 to 457)	12	16	54	18	MH	72	4.83	62	38	24
51	0 to 6 (0 to 152)	5	33	47	15	MH	62	0.67	51	45	6
	12 to 18 (305 to 457)	10	26	50	14	MH	64	1.11	60	41	19
52	0 to 6 (0 to 152)	11	16	57	16	MH	73	0.09	56	33	23
	12 to 18 (305 to 457)	2	24	59	15	ML	74	1.48	42	30	12
53	0 to 6 (0 to 152)	11	17	54	18	MH	72	2.36	55	35	20
	12 to 18 (305 to 457)	13	20	51	16	MH	67	3.74	55	44	11
54	0 to 6 (0 to 152)	10	24	44	22	CL	66	1.46	33	12	21
	6 to 12 (152 to 305)	12	17	53	18	MH	71	0.83	58	43	15
55	0 to 6 (0 to 152)	3	26	58	13	ML	71	2.97	34	27	7
	6 to 12 (152 to 305)	10	18	52	20	CL	72	1.32	34	10	24
56	0 to 6 (0 to 152)	5	23	56	16	MH	72	1.31	54	45	9
	6 to 12 (152 to 305)	11	17	59	13	MH	72	1.32	56	47	9
57	0 to 6 (0 to 152)	0	33	64	3	MH	67	0.74	60	51	9
	18 to 24 (457 to 610)	0	34	64	2	MH	66	1.63	54	46	8
58	0 to 6 (0 to 152)	0	37	58	5	MH	63	0.01	64	49	15
	12 to 18 (305 to 457)	0	40	58	2	MH	60	3.64	59	43	16
59	0 to 6 (0 to 152)	0	43	54	3	MH	57	2.21	59	49	10
	12 to 18 (305 to 457)	0	46	50	4	MH	54	3.06	61	46	15
60	0 to 6 (0 to 152)	0	43	52	5	MH	57	2.97	62	49	13
	12 to 18 (305 to 457)	0	40	55	5	MH	60	0.00	60	45	15
61	0 to 6 (0 to 152)	0	41	57	2	MH	59	0.40	55	39	16
	6 to 12 (152 to 305)	0	37	60	3	MH	63	1.11	73	46	27

Table B-3. Soil Description (concluded)

Crater Number	Soil Layer in (mm)	Mechanical Analysis Gravel %	Sand %	Silt %	Clay %	Unified Soil Classification System Classification	Fines %	Organic Matter %	Atterburg Limits LL %	PL %	PI %
62	0 to 6 (0 to 152)	0	42	52	6	MH	58	0.76	57	42	15
	6 to 12 (152 to 305)	0	39	56	5	MH	61	0.75	52	40	12
63	0 to 6 (0 to 152)	0	42	54	4	MH	58	0.06	55	46	9
	12 to 18 (305 to 457)	0	35	59	6	MH	65	0.00	58	47	11
64	0 to 6 (0 to 152)	0	35	60	5	MH	65	1.13	56	45	11
	18 to 24 (457 to 610)	0	34	62	4	MH	66	1.47	54	46	8
65	0 to 6 (0 to 152)	0	37	60	3	MH	63	0.62	55	46	9
	12 to 18 (305 to 457)	0	40	55	5	MH	60	0.04	59	42	17
66	0 to 6 (0 to 152)	0	35	61	4	MH	65	3.72	55	40	15
	12 to 18 (305 to 457)	0	41	55	4	MH	59	2.61	54	46	8

LL = Liquid Limit
PL = Plastic Limit
PI = Plastic Index
MH = Inorganic silts, elastic silts.
ML = Inorganic silts.
CH = Inorganic clays of high plasticity, fat clays.
OH = Organic clays of high plasticity, organic silts.
CL = Inorganic clays of low to medium plasticity.
SW = Coastal sands.
OL = Organic silts and organic silty clays of low plasticity.

TABLE B-4. CRATER BLOWOUT DATA

Crater Number	3 m: Material Weight (g)	3 m: Vegetation (%)	3 m: Soil (%)	6 m: Material Weight (g)	6 m: Vegetation (%)	6 m: Soil (%)	9 m: Material Weight (g)	9 m: Vegetation (%)	9 m: Soil (%)
	Distance from Detonation (meters)								
1 a/	3,247	52	48	364	99	1	228	76	24
2	2,549 b/	32	68	1,261	51	49	336	21	79
3	1,889	15	85	374	13	87	126	24	76
4	3,616	36	64	472	45	55	288	72	28
6	4,094	21	79	785	18	82	300	17	83
7	4,488	53	47	972	46	54	611	61	39
8	2,517	49	51	673	52	48	408	26	74
9	6,735	20	80	1,940	33	67	1,485	39	61
10	12,637	13	87	2,653	16	84	787	15	85
11	2,268	15	85	374	9	91	187	16	84
12	2,006	5	95	522	11	89	240	9	91
13	2,970	26	74	490	19	81	236	15	85
14	6,350	7	93	1,100	16	84	2,897	18	82
15	10,659	7	93	2,495	1	99	630	5	95
16	7,098	33	67	2,268	1	99	445	58	42
17	5,593	6	94	1,415	15	85	250	12	88
18	7,913	12	88	3,072	16	84	416	33	67
19	4,368	16	84	1,870	32	68	1,231	30	70
21	5,849	3	97	292	0	100	72	0	100
22	6,143	1	99	183	0	100	57	0	100
23	6,033	1	99	607	0	100	56	0	100
24	2,605 b/	1	99	680	6	94	91	0	100
25	[illegible]	25	75	614	45	55	98	17	83
26	[illegible]	33	67	371	89	11	151	67	33
27 d/	[illegible]	53	47	886	76	24	299	65	35
28 e/	3,206	5	95	321 f/	0	100	183	0	100
29 e/	2,401	5	95	612 g/	1	99	85 h/	0	100
30	5,596	40	60	1,108	43	57	258	36	64
31	6,640	24	76	941	12	88	603	32	68
32	3,514	9	91	645	47	53	197	36	64
33	2,546	12	88	1,559	7	93	550	44	56
34	1,072	30	70	569	4	96	235	27	73
35	3,357	16	84	1,110	9	91	336	12	88

Table B-4. Crater Blowout Data (concluded)

Crater Number	Distance from Detonation (meters): 3 — Material Weight (g)	3 — Vegetation (%)	3 — Soil (%)	6 — Material Weight (g)	6 — Vegetation (%)	6 — Soil (%)	9 — Material Weight (g)	9 — Vegetation (%)	9 — Soil (%)
36	2,651	24	76	703	48	52	471	45	55
37	7,884 b/	8	92	1,532	10	90	1,106	17	83
38	4,913	18	82	3,946	32	68	1,049	37	63
39	2,262	35	65	405	31	69	388	23	77
40	2,619	23	77	403	27	73	297	51	49
41	7,890	21	79	1,060	41	59	594	51	49
42	4,060	8	92	575	21	79	198	47	53
43	4,578	15	85	802	1	99	273	20	80
44	8,858	7	93	1,071	4	96	352	9	91
45	6,430	7	93	6,146	13	87	422	46	54
46	8,322	3	97	7,085	9	91	182	18	82
47	4,306	45	55	865	12	88	488	59	41
48	3,022	25	75	1,558	16	84	780	28	72
49	6,469	19	81	1,959	18	82	747	36	64
50	2,757	26	74	806	47	53	177	27	73
57	6,061	12	88	908	34	66	365	14	86
58	4,281	56	44	1,282	55	45	263	13	87
59	4,196	20	80	1,219	71	29	416	27	73
60	13,778	15	85	2,339	23	77	1,319	39	61
61	2,325	24	76	320	23	77	216	22	78
62	2,240	32	68	692	40	60	232	25	75
63	1,049	33	67	2,580	40	60	202	30	70
64	7,258	19	81	2,070	0	100	1,644	0	100
65	11,227	17	83	1,786	41	59	464	8	92
66	8,051	9	91	1,729	45	55	694	0	100

a/ Boards were placed at 5-, 10-, and 15-meter intervals for this crater only.

b/ Material collected on three boards; one board was overturned by blast.

c/ Material collected on two boards; two boards were overturned by blast.

d/ Lost approximately 15 percent of material because of rain.

e/ Boards were placed on only three radii.

f/ 100 percent of the material was lost from one board because of wave action.

g/ 90 percent of the material was lost from one board because of wave action.

h/ 90 percent of the material was lost from two boards because of wave action.

TABLE B-5. CLOUD GROWTH DATA

Crater Number	Obscured Area Seconds After Detonation 1	2	5	10	20	40	Cloud Center Coordinates (Blast Site = 0,0) X_1	X_2	X_5	X_{10}	X_{20}	X_{40}	Y_1	Y_2	Y_5	Y_{10}	Y_{20}	Y_{40}
			(m²)							(m)								
1	50	67	138	248	0	0	0	3	12	19	—	—	2	2	4	5	—	—
2	39	100	455	994	1,440	0	2	1	8	21	17	—	3	4	5	8	10	—
3	101	753	819	1,895	0	0	2	5	10	-8	—	—	3	6	10	17	—	—
4	31	185	304	1,179	1,681	0	1	3	8	-6	3	—	2	3	5	8	13	—
6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
7	56	80	151	62	0	0	0	1	3	-2	—	—	4	5	6	8	—	—
8	58	49	77	115	0	0	1	6	5	7	—	—	3	5	3	5	—	—
9	294	308	74	99	59	0	0	-3	0	0	-5	—	3	5	3	3	2	—
10	124	82	56	117	66	0	0	0	-1	-3	-13	—	2	2	4	0	0	—
11	82	81	0	0	0	0	-2	-1	—	—	—	—	5	3	—	—	—	—
12	262	227	251	212	218	0	-2	-1	-3	-5	-8	—	4	5	6	12	22	—
13	58	45	80	0	0	0	1	1	-2	—	—	—	2	2	2	—	—	—
14	215	128	289	465	0	0	2	-3	-7	17	—	—	5	6	7	7	—	—
15	256	217	497	867	0	0	0	0	-4	-12	—	—	6	8	9	8	—	—
16	45	123	69	71	100	0	1	6	5	2	-7	—	2	3	4	4	6	—
17	147	401	669	399	0	0	-5	-7	-12	-11	—	—	4	5	7	17	—	—
18	395	462	379	852	88	0	0	0	-4	0	1	—	2	3	4	5	7	—
19	91	40	70	44	32	0	-1	7	6	8	14	—	1	1	1	2	3	—
20	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
21	223	258	591	197	0	0	-4	-7	3	3	—	—	4	5	14	22	—	—
22	109	272	681	492	0	0	-3	-6	-3	-4	—	—	5	6	11	3	—	—
23	118	216	311	328	0	0	0	-1	-7	0	—	—	5	4	15	33	—	—
24	155	457	119	65	0	0	0	3	5	13	—	—	5	8	23	9	—	—
25	311	408	631	1,907	0	0	0	-2	-2	0	—	—	5	8	8	22	—	—
26	357	458	619	1,631	0	0	0	4	8	10	—	—	4	7	11	19	—	—
27	144	214	83	0	0	0	5	3	17	—	—	—	4	5	11	—	—	—
28	220	299	340	698	0	0	0	-1	1	-1	—	—	4	7	18	20	—	—
29	190	208	358	0	0	0	0	-1	5	—	—	—	4	7	16	—	—	—
30	240	407	691	150	0	0	9	8	13	12	—	—	6	7	9	10	—	—
31	115	215	388	147	0	0	0	0	2	-2	—	—	4	5	9	8	—	—
32	54	81	878	461	607	0	7	10	38	36	26	—	2	2	0	3	8	—
33	72	258	326	143	0	0	2	1	-6	-4	—	—	3	3	4	5	—	—
34	58	56	0	0	0	0	4	4	—	—	—	—	2	3	—	—	—	—
35	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
36	114	127	356	936	0	0	0	-3	3	6	—	—	4	5	7	8	—	—
37	58	151	193	191	369	0	5	0	2	6	7	—	2	3	2	4	12	—
38	49	61	93	93	0	0	-1	-3	-3	-6	—	—	2	2	2	2	—	—
39	70	91	210	87	0	0	-4	-3	0	5	—	—	2	2	1	2	—	—
40	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
41	28	46	67	0	0	0	6	5	8	—	—	—	1	0	2	—	—	—
42	80	170	298	989	0	0	0	0	-3	-5	—	—	2	4	7	17	—	—
43	196	245	462	689	1,554	0	0	0	1	3	-1	—	4	4	5	7	11	—
44	40	95	397	311	0	0	-1	0	0	-4	—	—	1	2	2	4	—	—

Table B-5. Cloud Growth Data (concluded)

Crater Number	Obscured Area Seconds After Detonation (m²) 1	2	5	10	20	40	Cloud Center Coordinates (Blast Site = 0,0) (m) X_1	X_2	X_5	X_{10}	X_{20}	X_{40}	Y_1	Y_2	Y_5	Y_{10}	Y_{20}	Y_{40}
45	39	139	338	519	1,561	0	0	1	3	6	7	—	1	2	5	8	16	—
46	133	277	516	843	519	0	-1	1	0	-1	-1	—	5	6	6	7	13	—
47	30	55	273	778	1,091	0	0	1	2	-2	-2	—	2	2	3	4	5	—
48	75	134	414	0	0	0	0	0	-6	—	—	—	2	3	3	—	—	—
49	208	313	260	0	0	0	0	-3	-6	—	—	—	0	3	4	—	—	—
50	82	365	478	307	191	0	3	1	-14	-17	-11	—	2	2	4	7	17	—
51	39	47	69	60	698	1,395	1	1	1	-7	-3	3	1	1	3	10	15	19
52	81	113	105	106	218	891	0	-11	-13	-13	-14	-13	3	4	4	3	7	13
53	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
54	41	60	51	0	0	0	4	6	3	—	—	—	1	2	2	—	—	—
55	32	131	73	62	65	53	0	0	0	2	2	5	8	8	7	8	9	8
56	49	57	119	524	469	127	-1	1	5	5	-3	19	3	3	5	7	10	6
57	168	565	545	1,421	0	0	4	-3	-7	-12	—	—	5	6	7	14	—	—
58	205	425	561	693	0	0	1	1	-4	-13	—	—	2	3	5	16	—	—
59	275	331	424	288	0	0	0	1	3	-6	—	—	3	4	5	8	—	—
60	196	574	794	818	0	0	0	0	0	-3	—	—	2	3	5	9	—	—
61	122	805	916	1,435	0	0	5	12	13	15	—	—	3	8	10	13	—	—
62	76	61	122	0	0	0	1	-3	5	—	—	—	2	3	3	—	—	—
63	106	87	42	0	0	0	0	0	1	—	—	—	2	2	2	—	—	—
64	126	103	53	62	0	0	2	1	0	0	—	—	2	3	2	3	—	—
65	78	99	61	0	0	0	1	1	0	—	—	—	2	4	4	—	—	—
66	275	487	218	101	0	0	3	0	0	2	—	—	6	10	9	7	—	—

NOTE: For those entries with dashes, data could not be computed from video coverage.

APPENDIX C. PROFILES AND PHOTOGRAPHS

The crater profiles shown in this Appendix are all at the same scale (10-centimeter increments). Crater diameters were measured by laying a survey rod (A to B) across the approximate center of the crater at the original ground level. Vertical distances (from the rod to the crater floor) were recorded at 10-centimeter increments. For asymmetric craters, additional measurements were recorded in the same manner by laying another rod (C to D) perpendicular to the first. In some cases, loose material was scooped out (after the initial measurements) and the [illegible] were measured to determine the amount of fallback material.

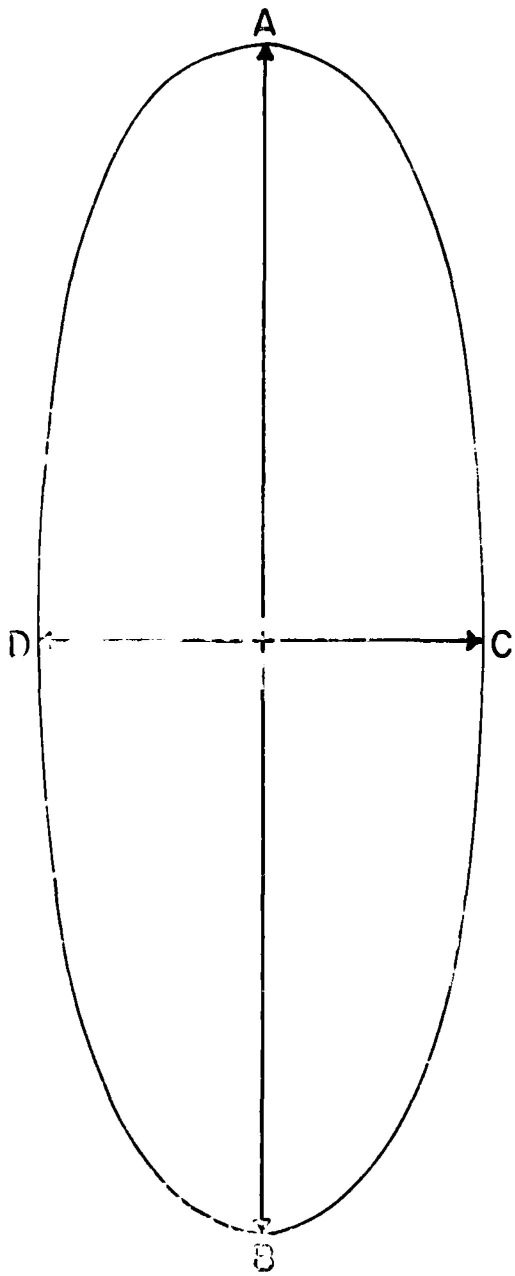


Figure C-1. Crater Measurement Survey Points.

Part C-1. Selected Crater Profiles and Photographs

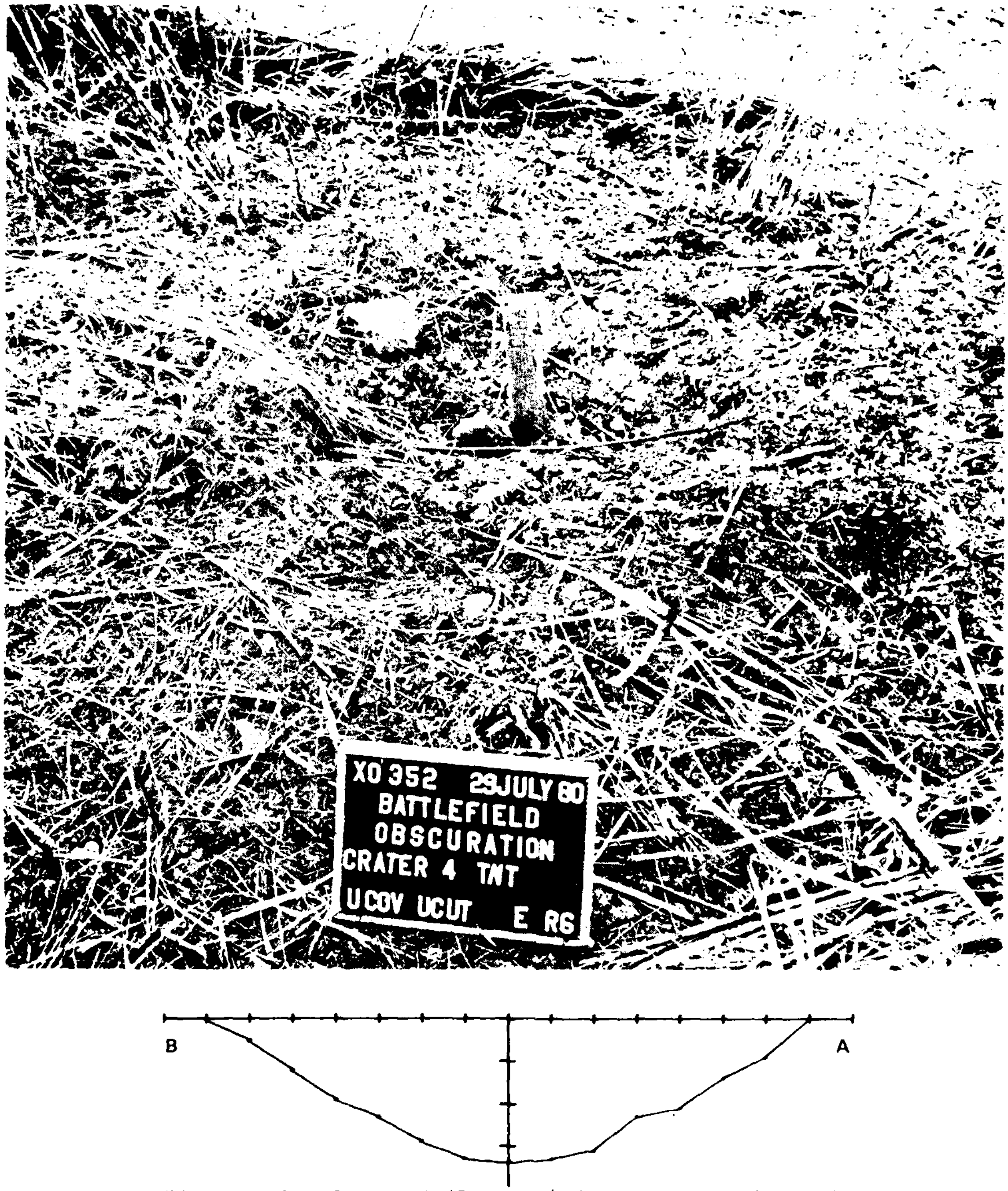


Figure C-2. Crater 4 (Range 6) Site and Profile--TNT.

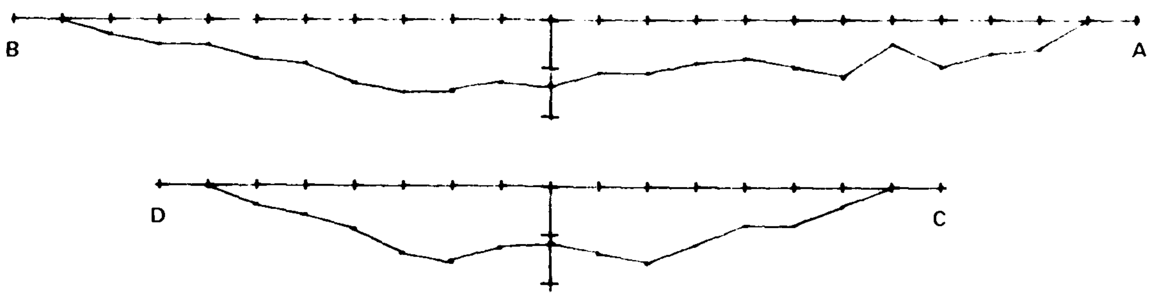
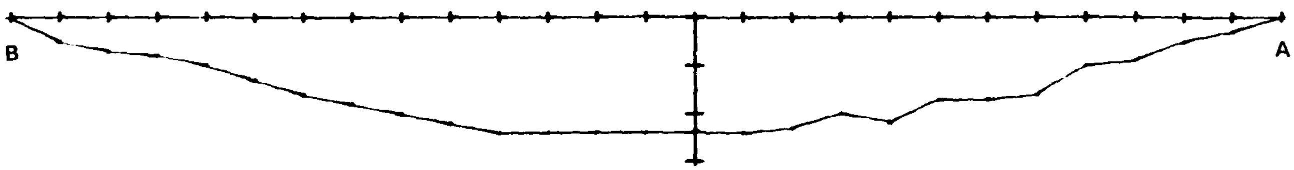


Figure C-3. Crater 7 (Range 6) Site and Profiles--105mm Round.



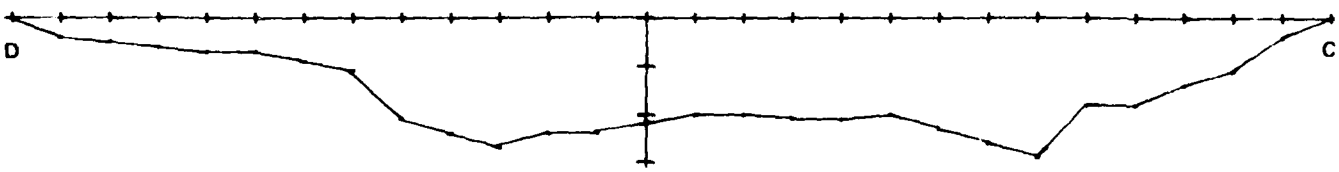


Figure C-4. Crater 9 (Range 6) Site and Profiles--155mm Round.

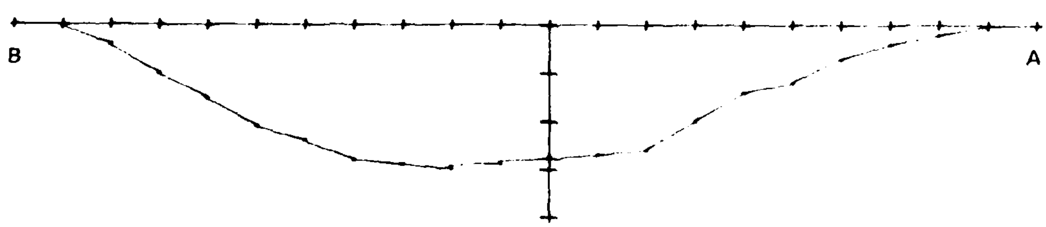


Figure C-5. Crater 22 (Pina Beach) Site and Profile--TNT.

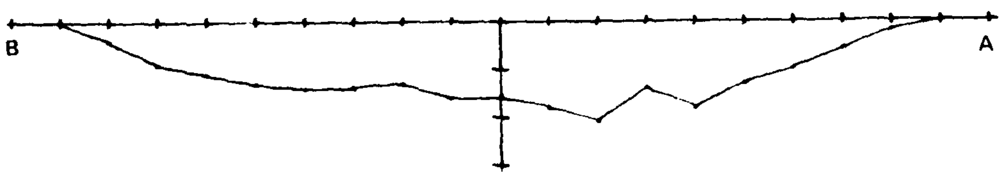


Figure C-6. Crater 55 (Range 6; Low Canopy) Site and Profile--155mm Round.

Part C-2. Representative With/Without Fallback Profile Comparisons

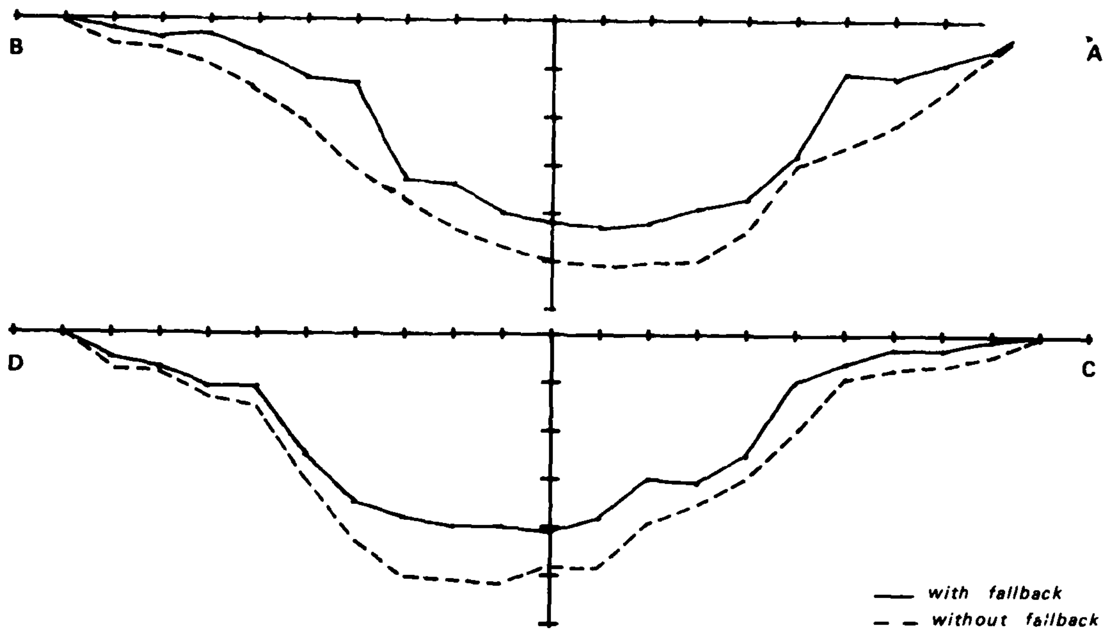


Figure C-7. Crater 59 (TNT--Mindi) Profile Comparisons--With and Without Fallback.

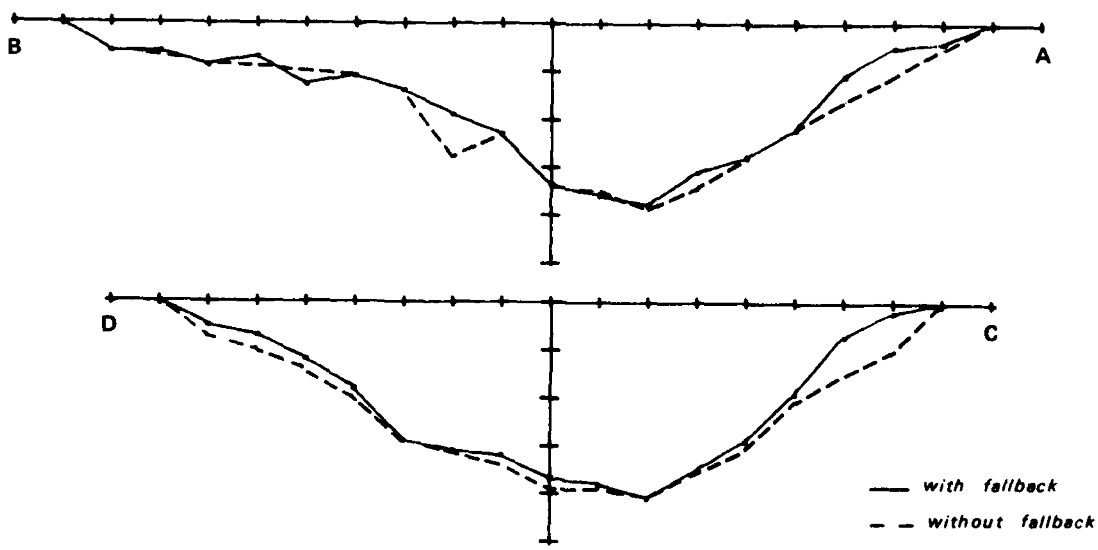


Figure C-8. Crater 63 (105mm--Mindi) Profile Comparisons--With and Without Fallback.

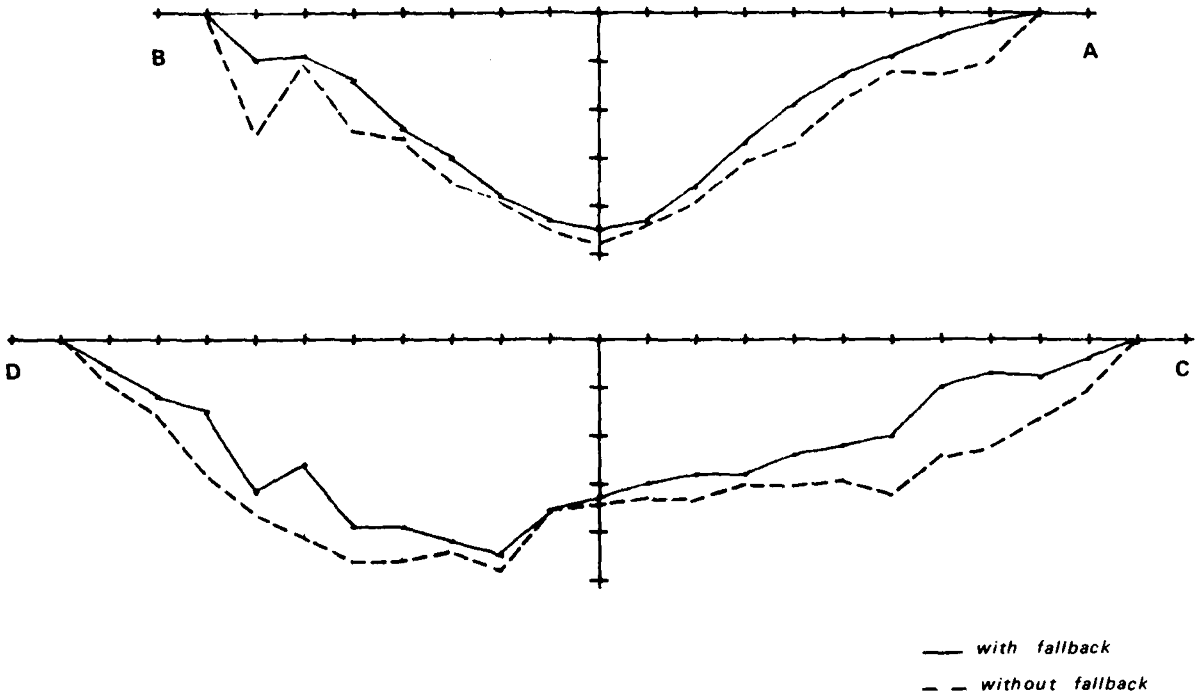


Figure C-9. Crater 66 (155mm--Mindi) Profile Comparisons--With and Without Fallback.

Part C-3. Crater Profiles (1-66)

(NOTE: With and without fallback profiles do not necessarily overlap because they were measured from rim to rim instead of from a reference point.)

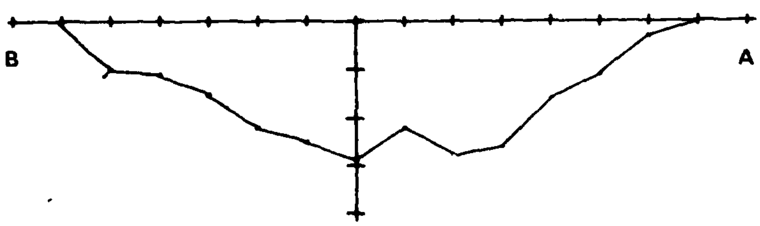


Figure C-10. Crater 1 (TNT).

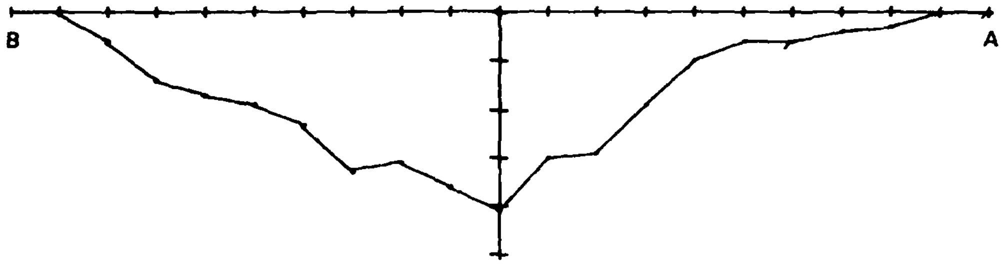


Figure C-11. Crater 2 (TNT).

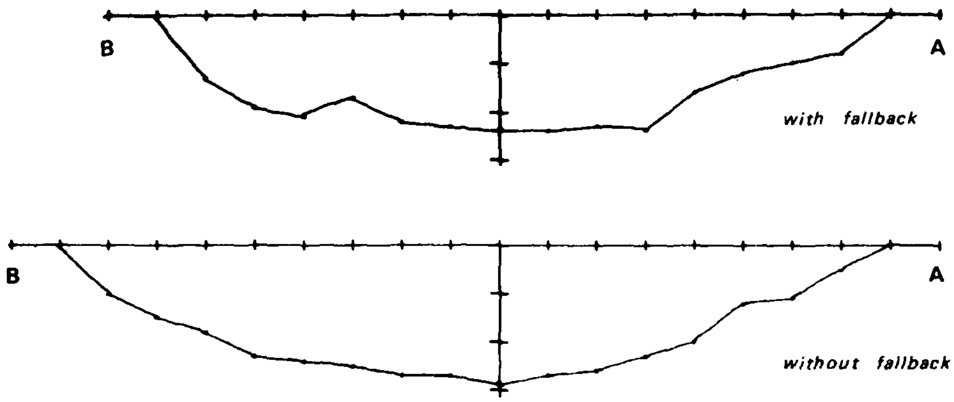


Figure C-12. Crater 3 (TNT).

(Crater 4--See figure C-2.)

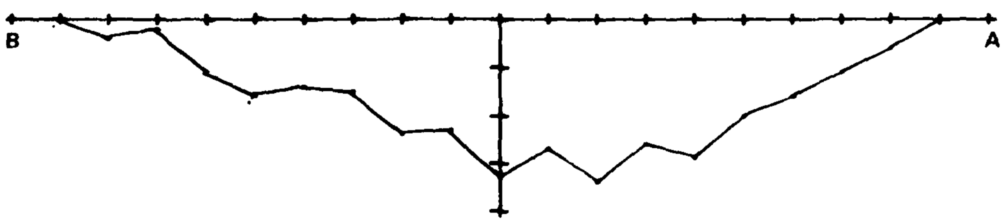


Figure C-13. Crater 5 (TNT).

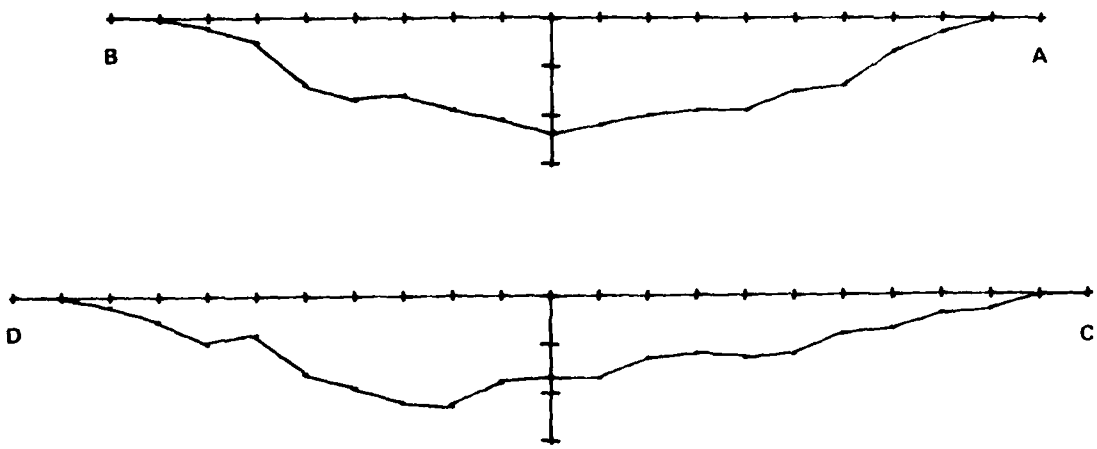


Figure C-14. Crater 6 (105mm).

(Crater 7--See figure C-3.)

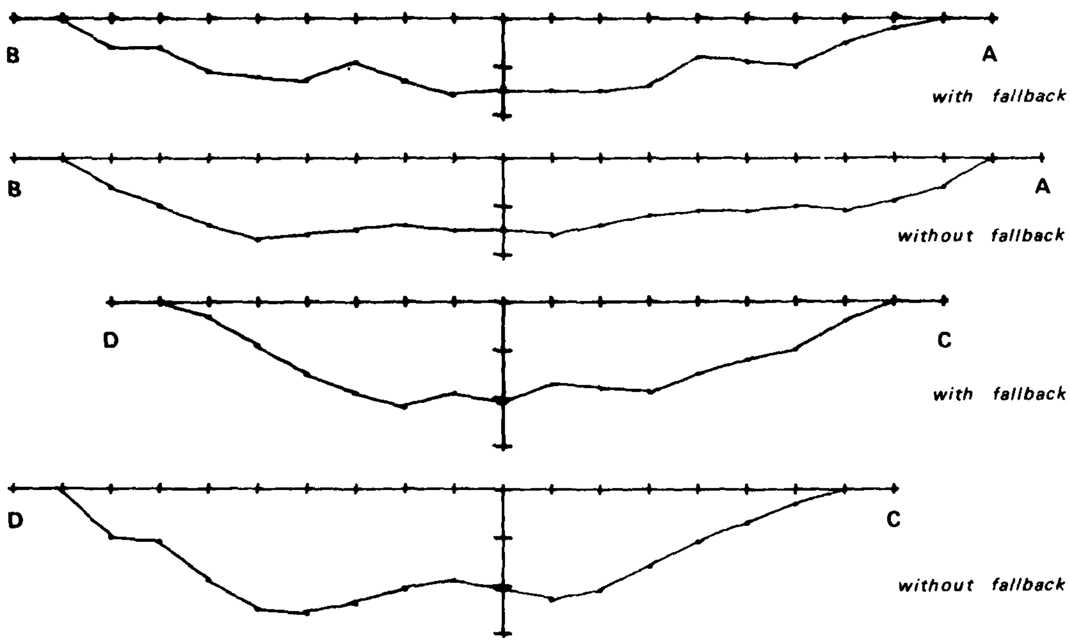


Figure C-15. Crater 8 (105mm).

(Crater 9--See figure C-4.)

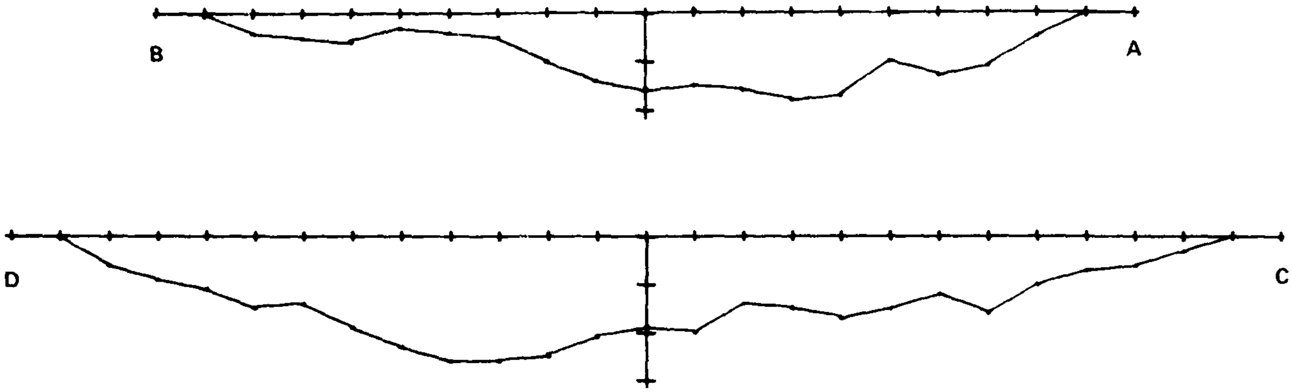


Figure C-16. Crater 10 (155mm).

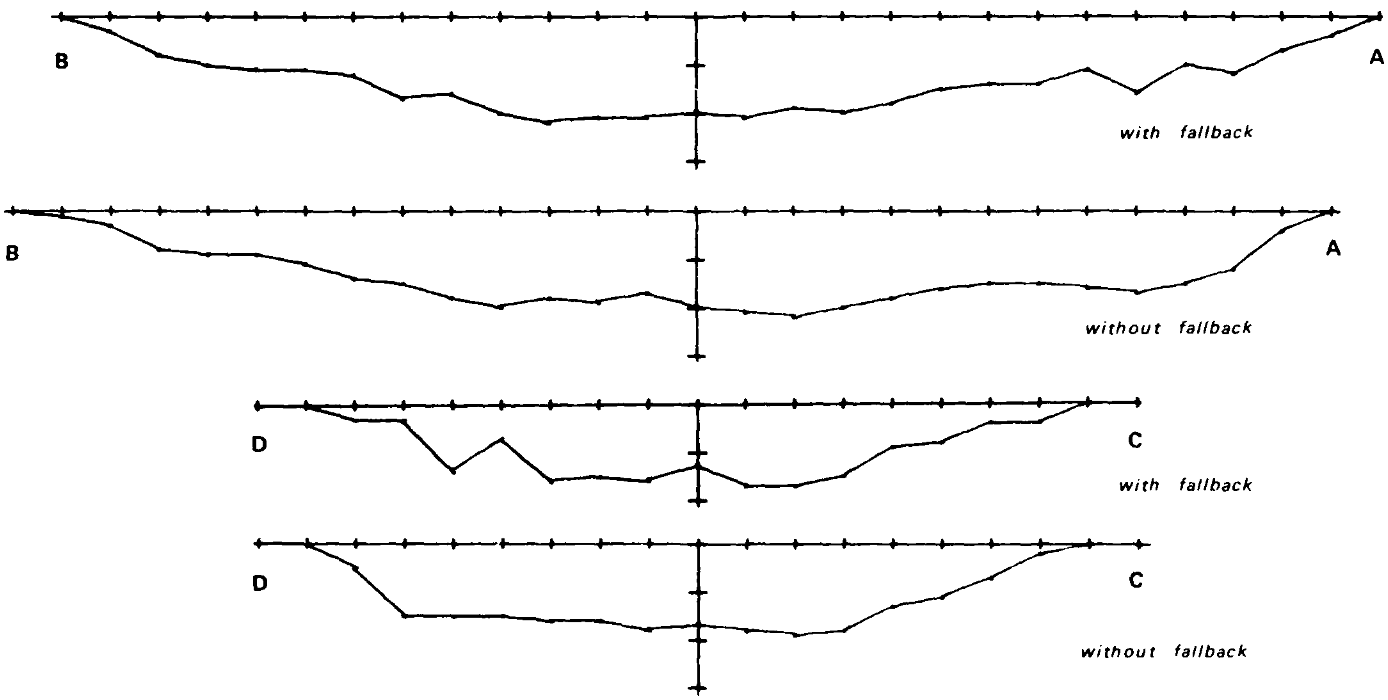


Figure C-17. Crater 11 (105mm).

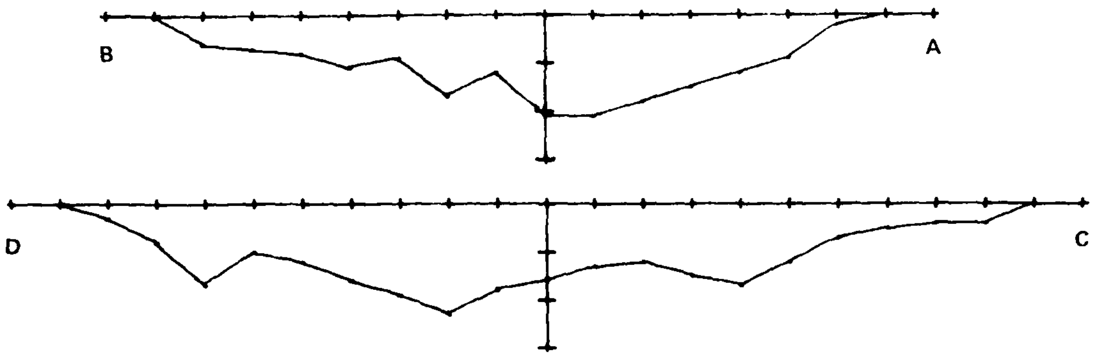


Figure C-18. Crater 12 (105mm).

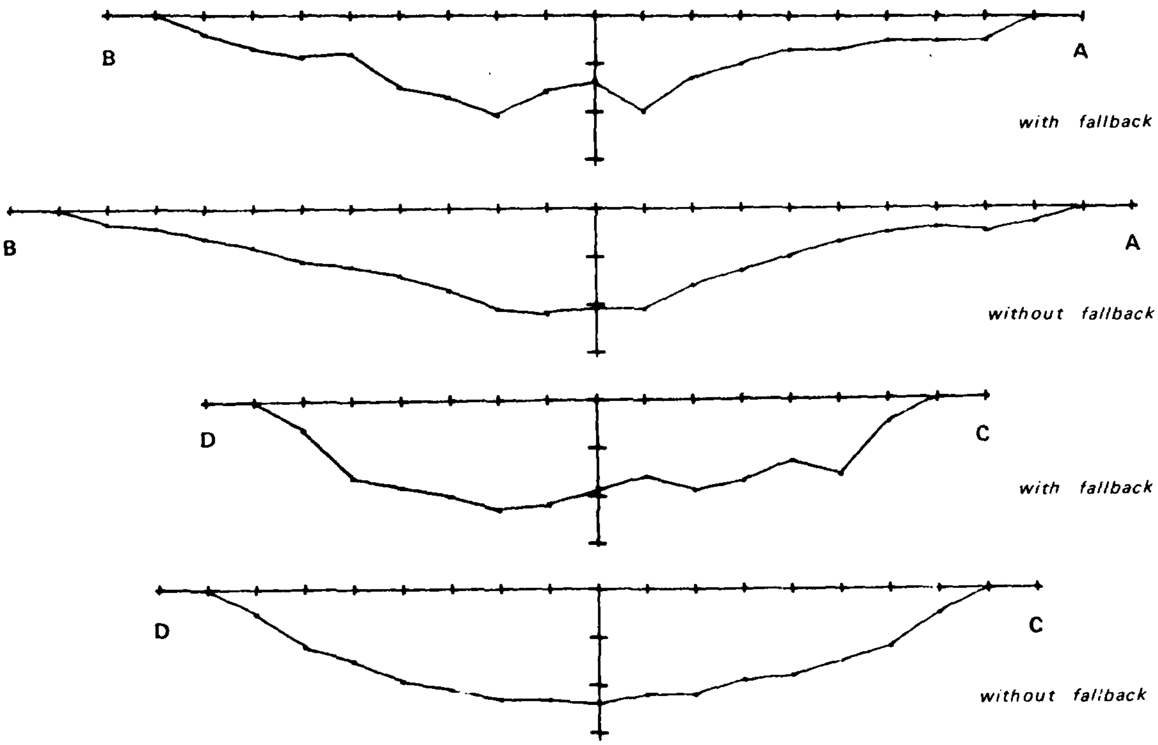


Figure C-19. Crater 13 (105mm).

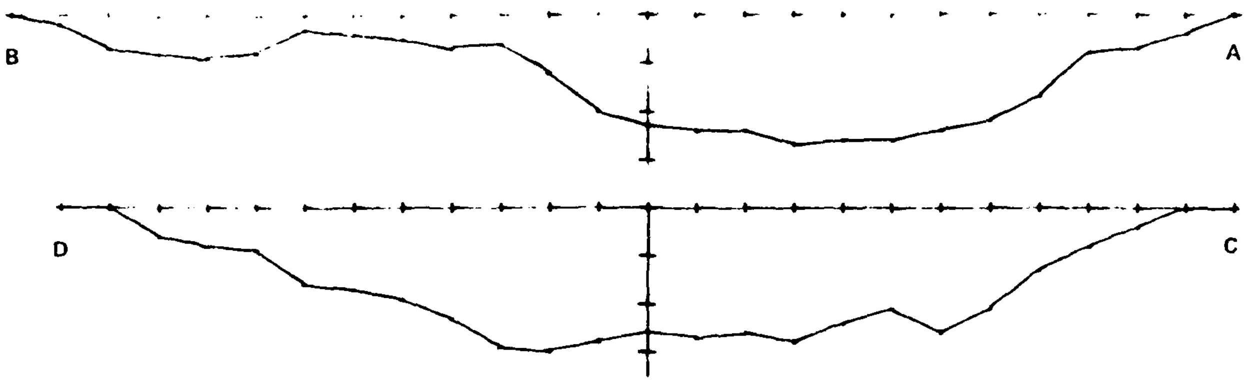


Figure C-20. Crater 14 (155mm).

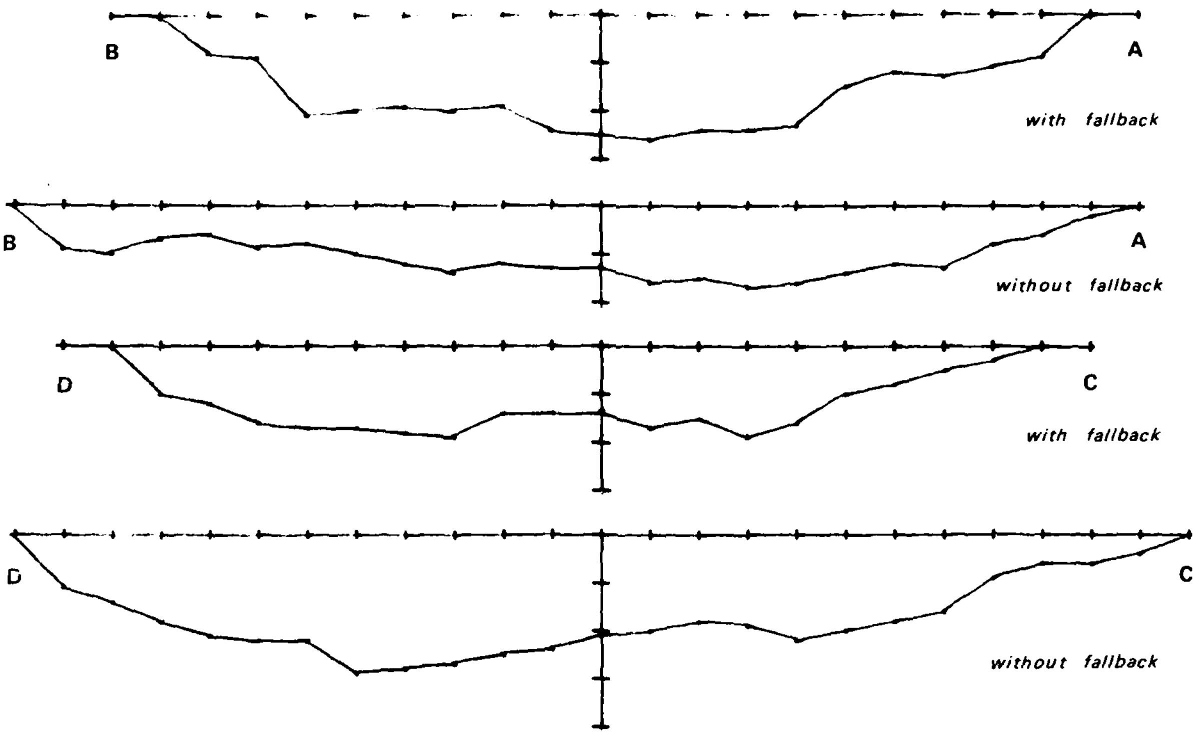


Figure C-21. Crater 15 (155mm).

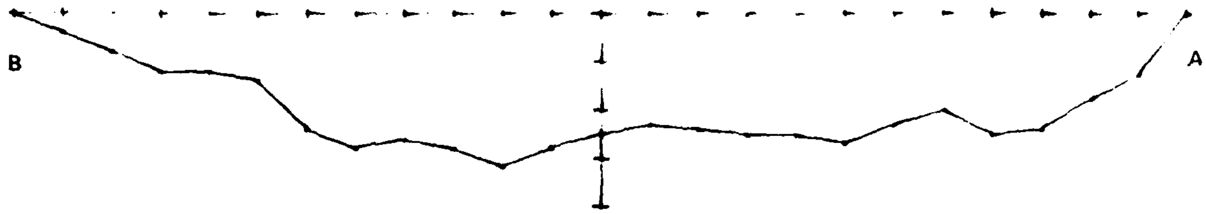


Figure C-22. Crater 16 (155mm).

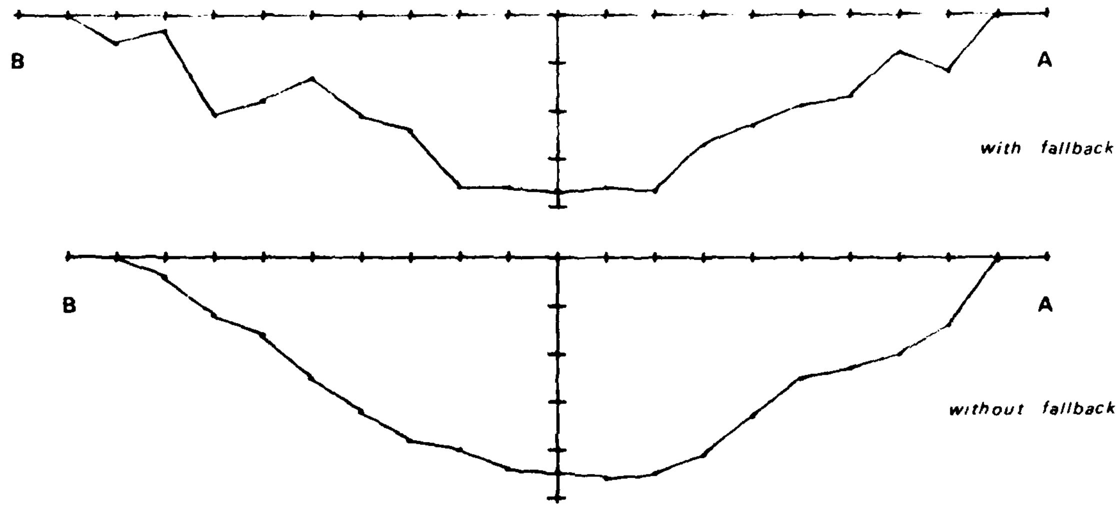


Figure C-23. Crater 17 (TNT).

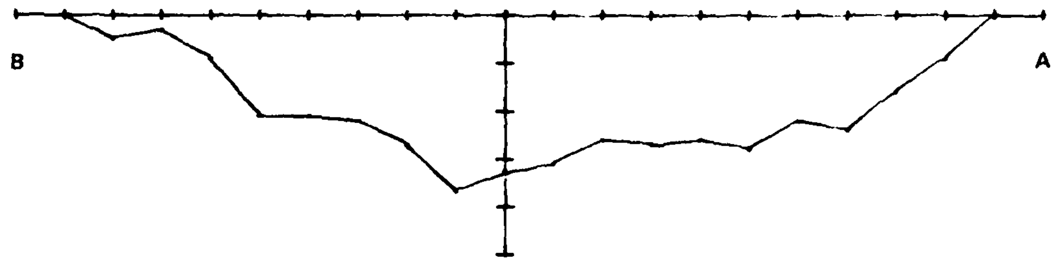


Figure C-24. Crater 18 (TNT).

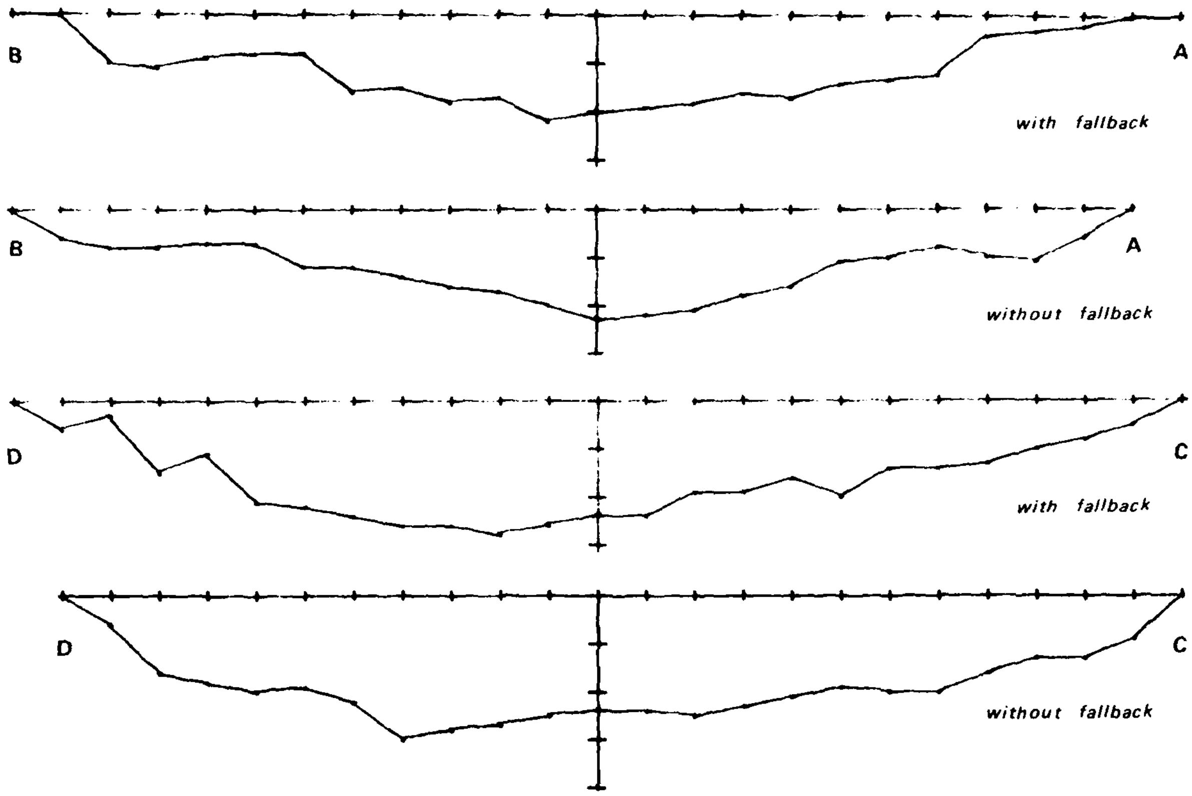


Figure C-25. Crater 19 (155mm).

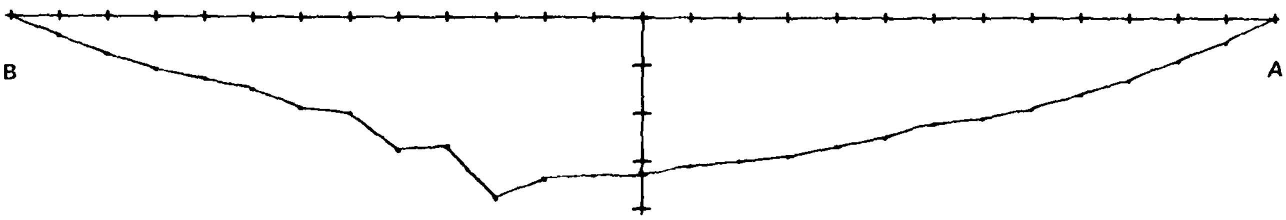


Figure C-26. Crater 20 (155mm).

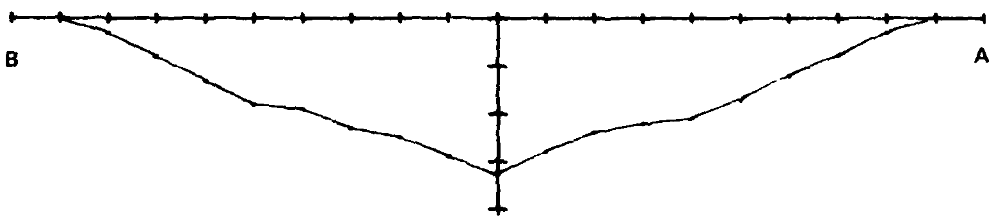


Figure C-27. Crater 21 (TNT).

(Crater 22--See figure C-5.)

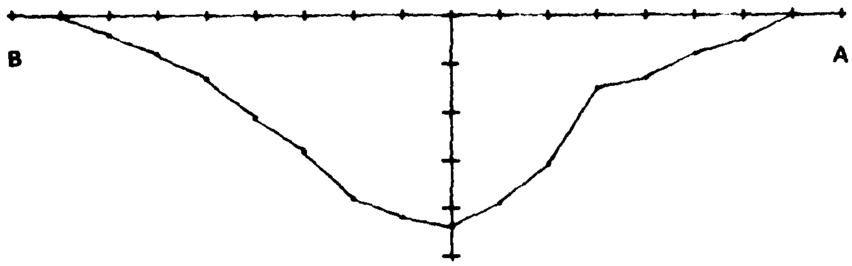


Figure C-28. Crater 23 (TNT).

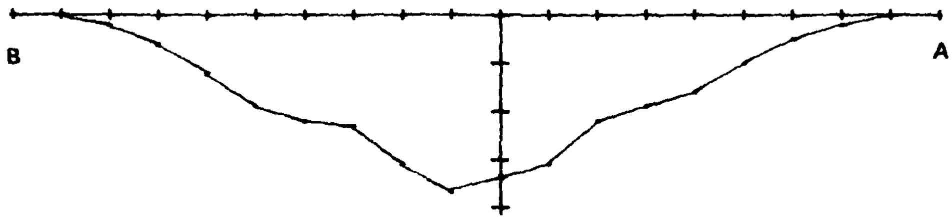


Figure C-29. Crater 24 (TNT).

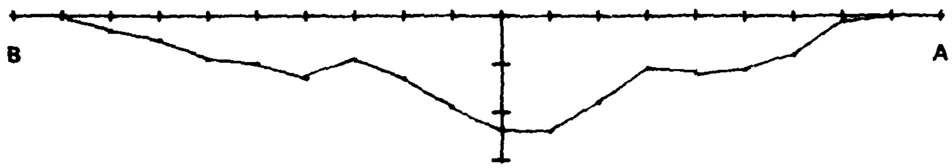


Figure C-30. Crater 25 (TNT).

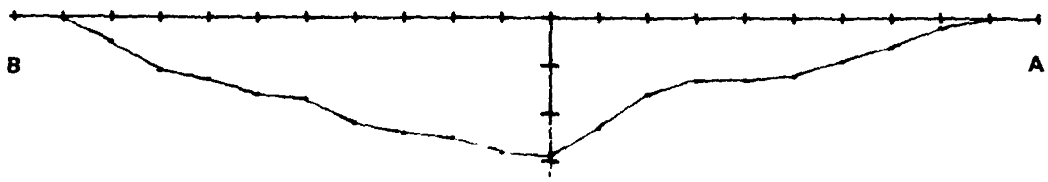


Figure C-31. Crater 26 (TNT).

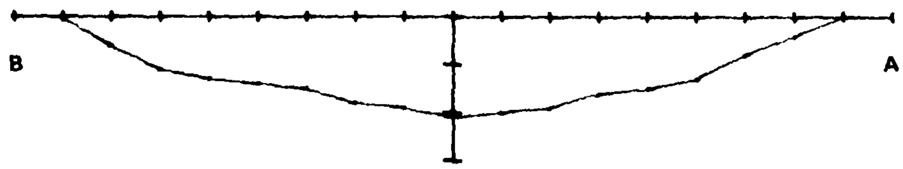


Figure C-32. Crater 27 (TNT).

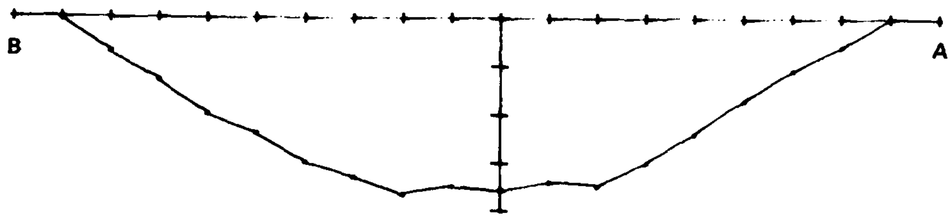


Figure C-33. Crater 28 (TNT).

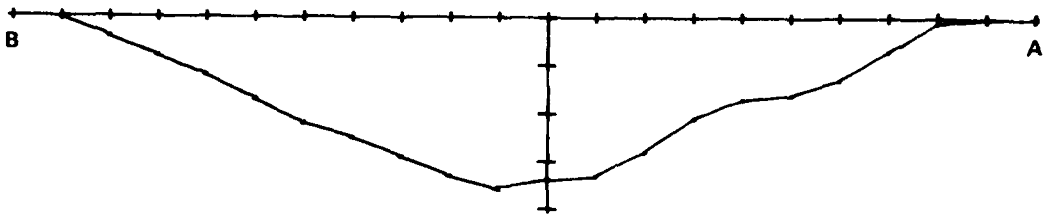


Figure C-34. Crater 29 (TNT).

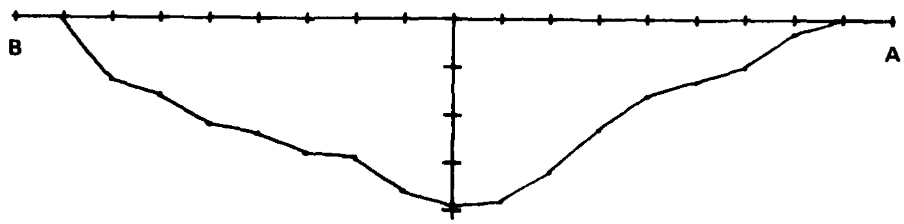


Figure C-35. Crater 30 (TNT).

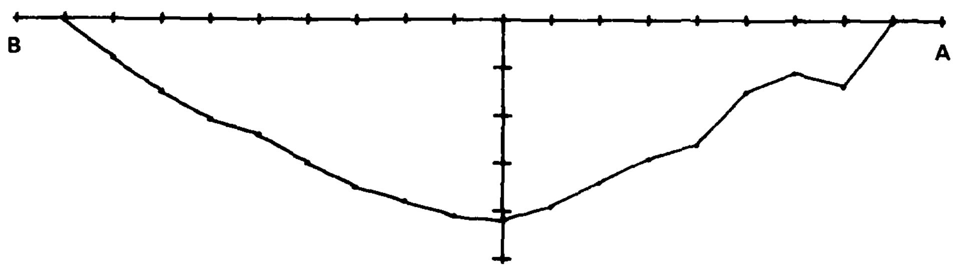


Figure C-36. Crater 31 (TNT).

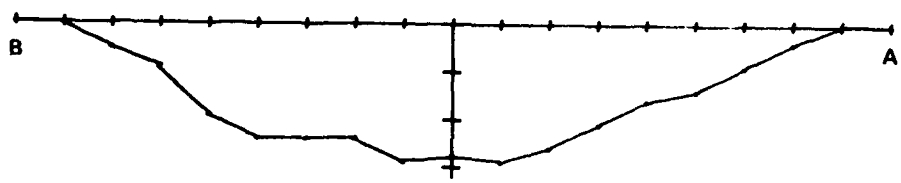


Figure C-37. Crater 32 (TNT).

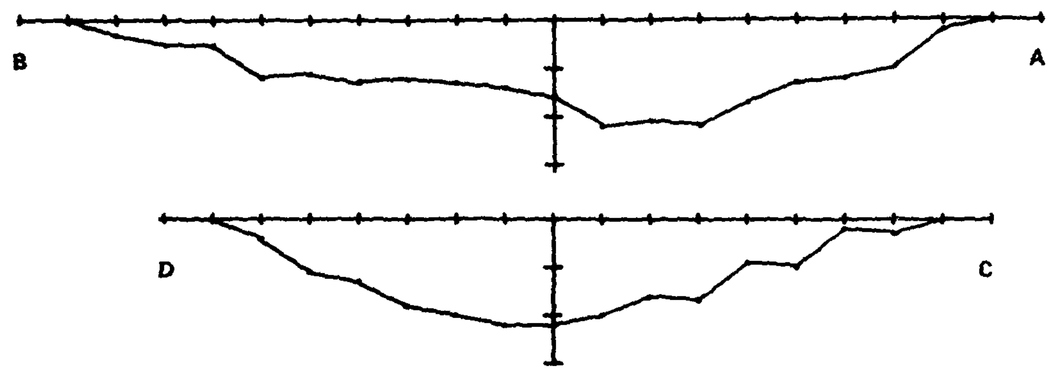


Figure C-38. Crater 33 (105mm).

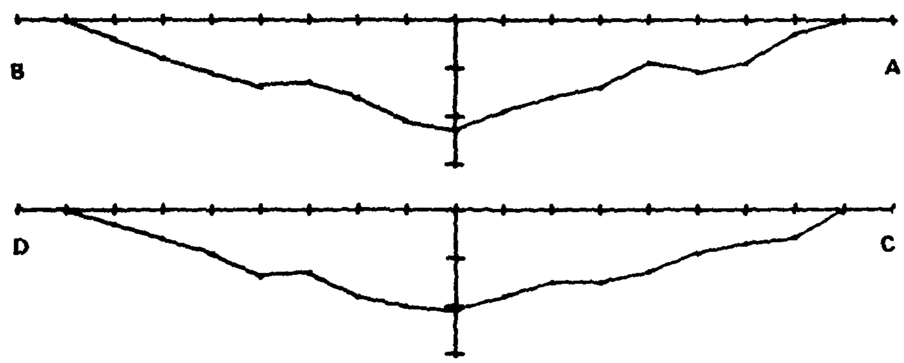


Figure C-39. Crater 34 (105mm).

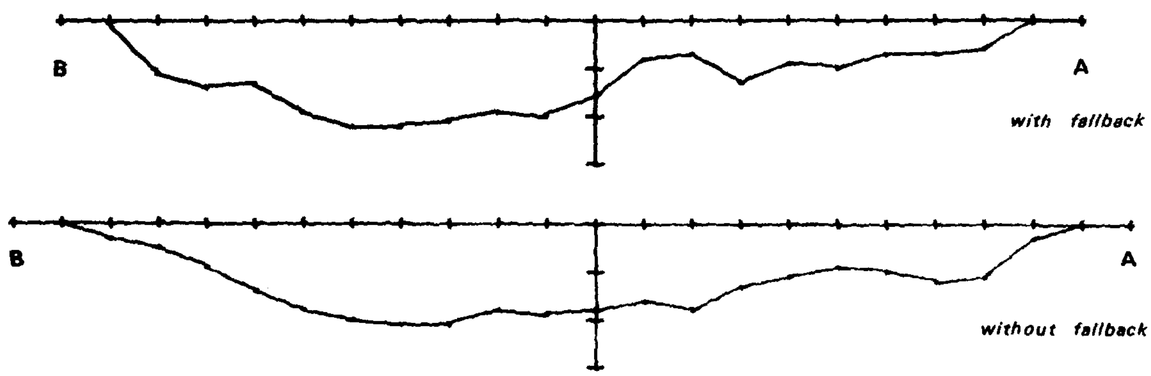


Figure C-40. Crater 35 (105mm).

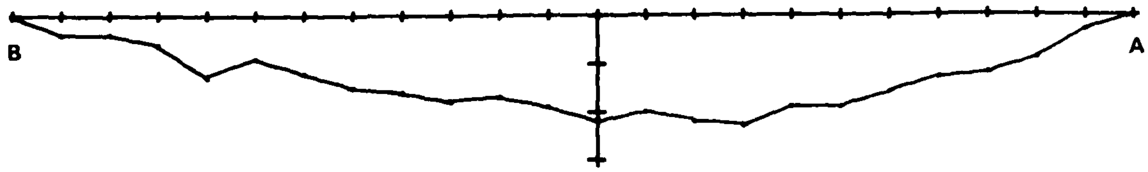


Figure C-41. Crater 36 (155mm).

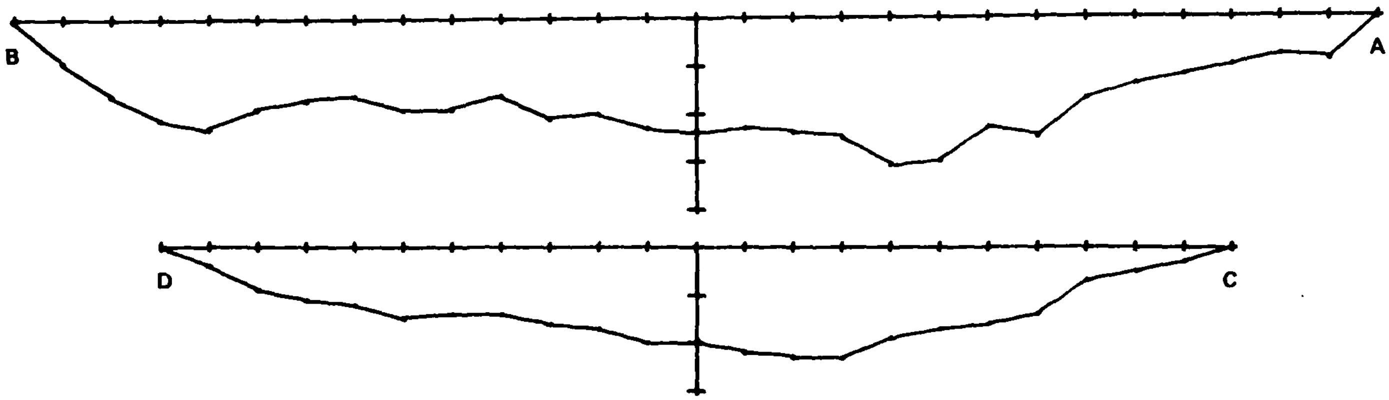


Figure C-42. Crater 37 (155mm).

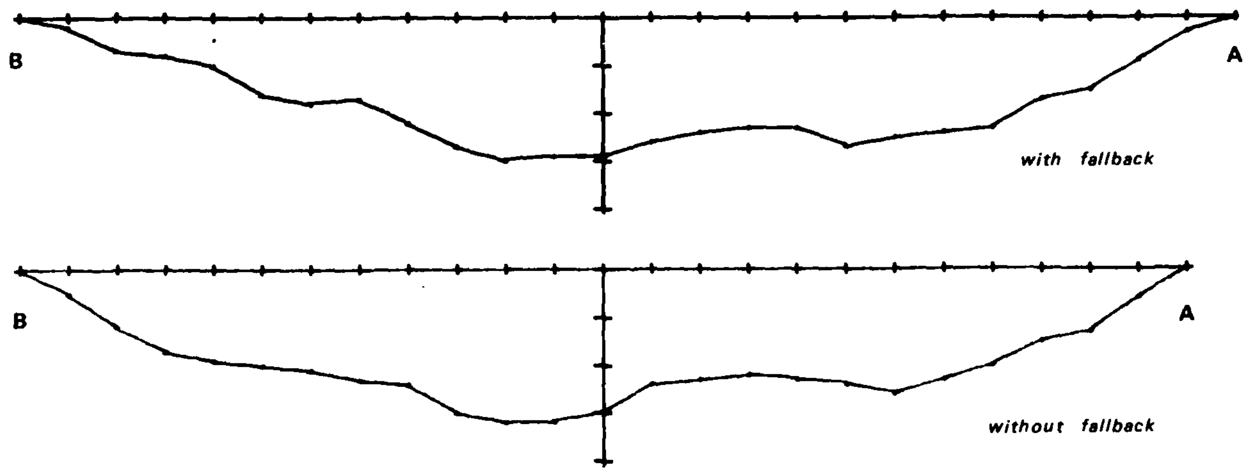


Figure C-43. Crater 38 (155mm).

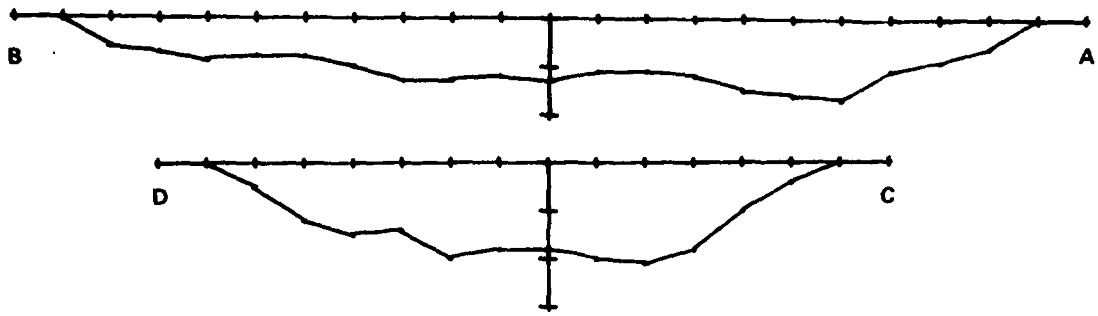


Figure C-44. Crater 39 (105mm).

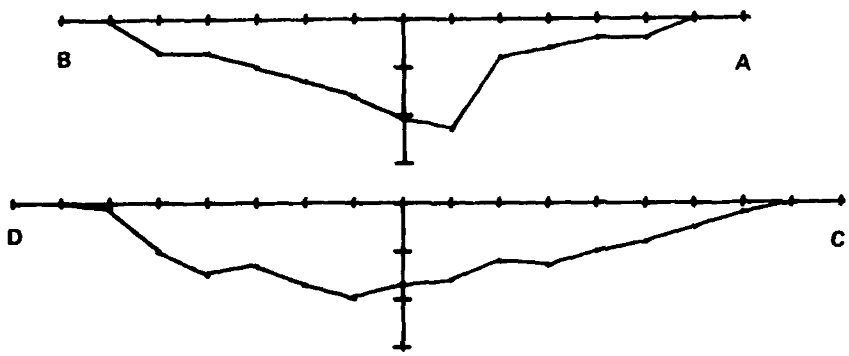


Figure C-45. Crater 40 (105mm).

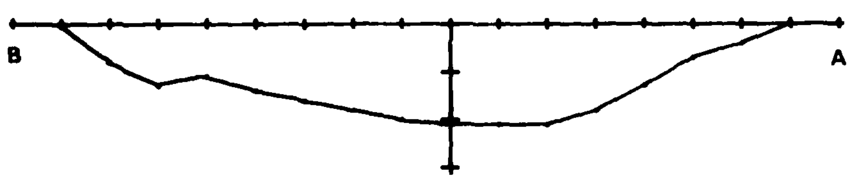


Figure C-46. Crater 41 (105mm).

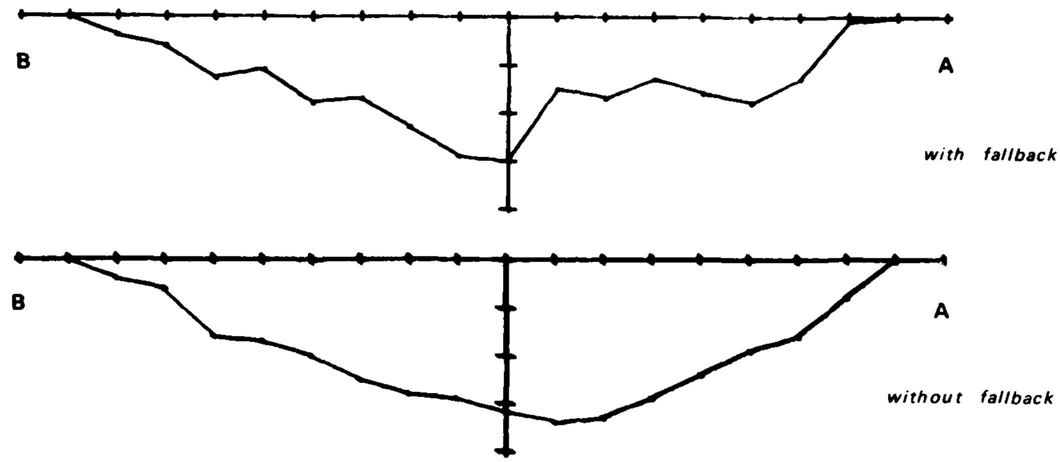


Figure C-47. Crater 42 (TNT).

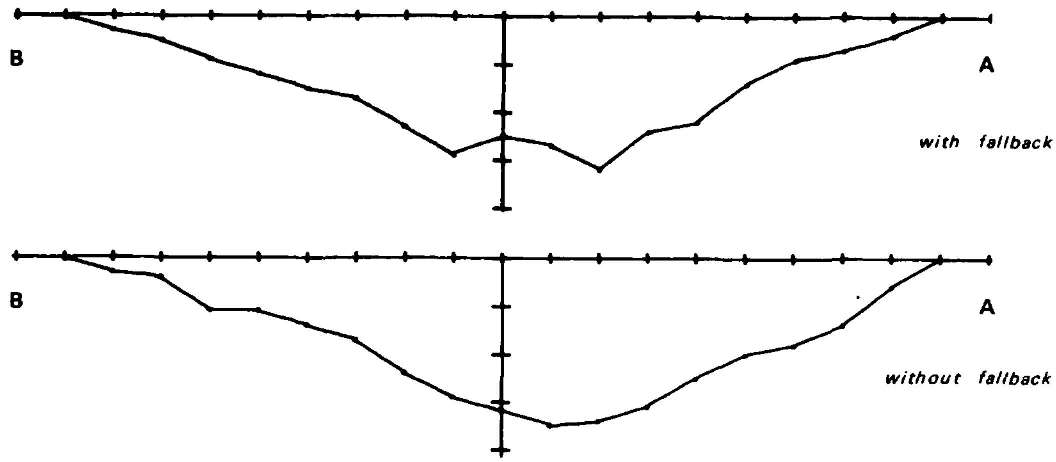


Figure C-48. Crater 43 (TNT).

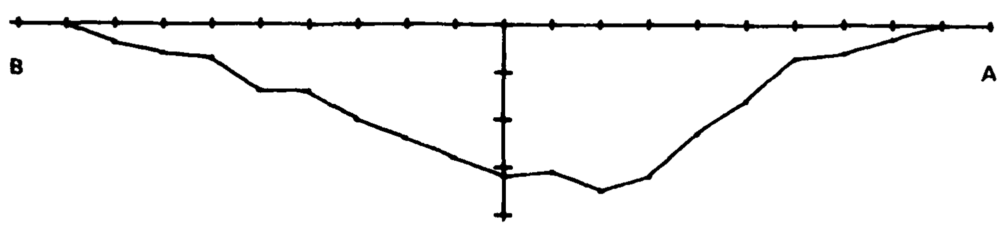


Figure C-49. Crater 44 (TNT).

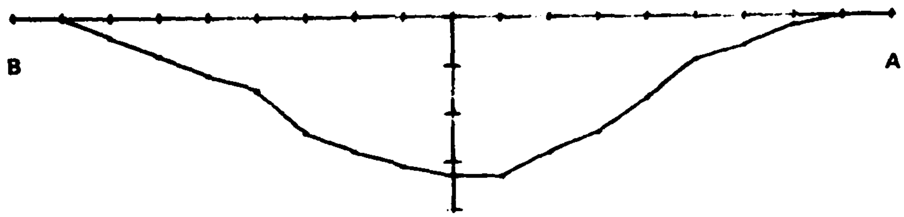


Figure C-50. Crater 45 (TNT).

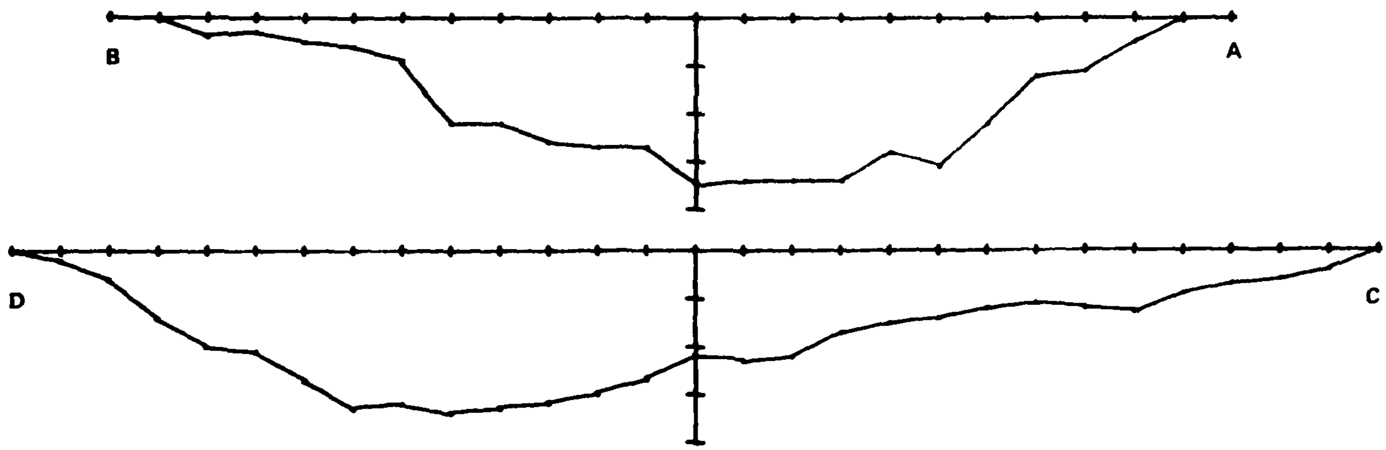


Figure C-51. Crater 46 (155mm).

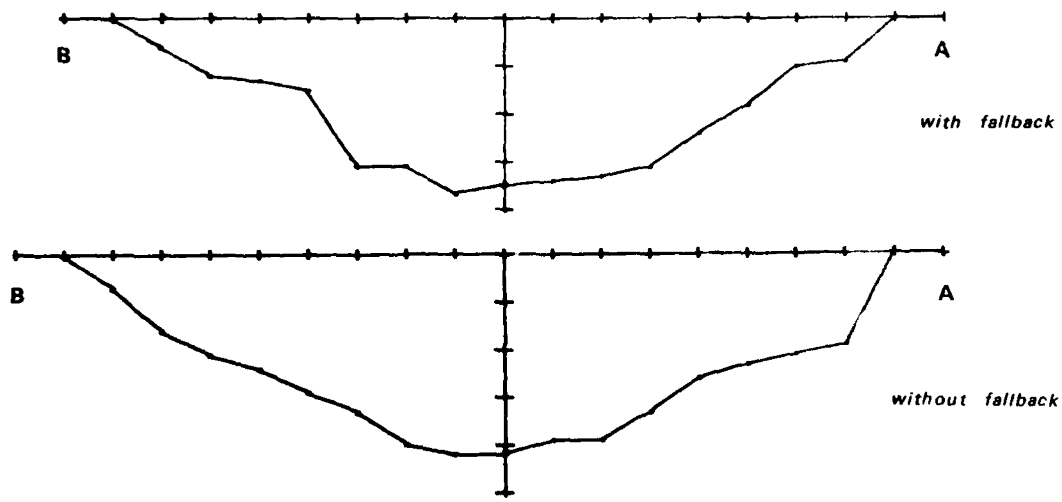


Figure C-52. Crater 47 (TNT).

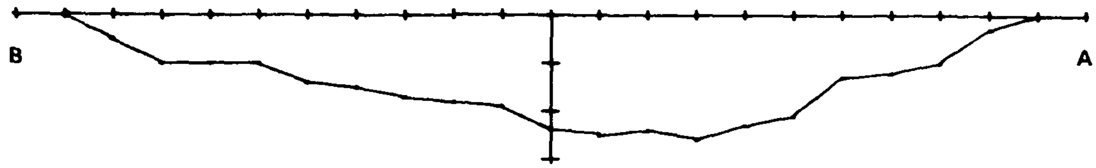


Figure C-53. Crater 48 (155mm).

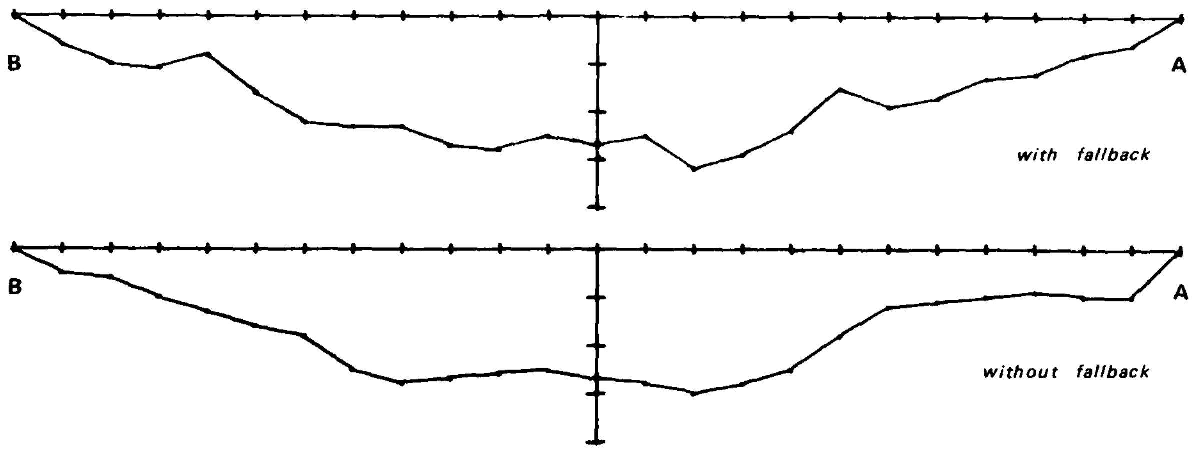


Figure C-54. Crater 49 (155mm).

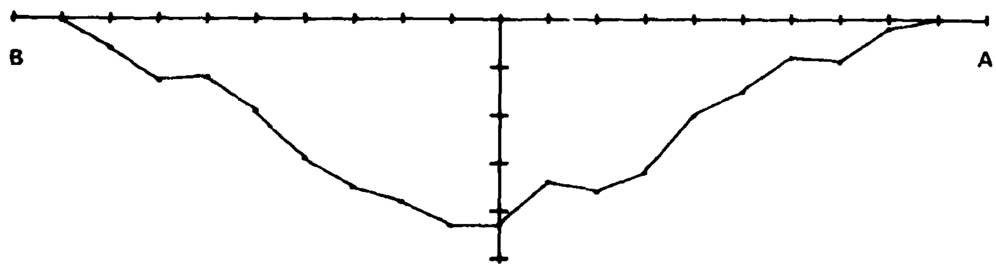


Figure C-55. Crater 50 (TNT).

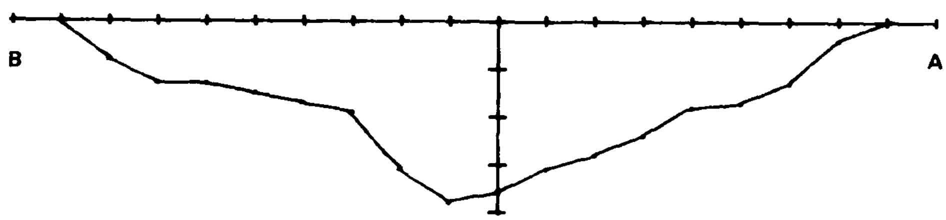


Figure C-56. Crater 51 (TNT).

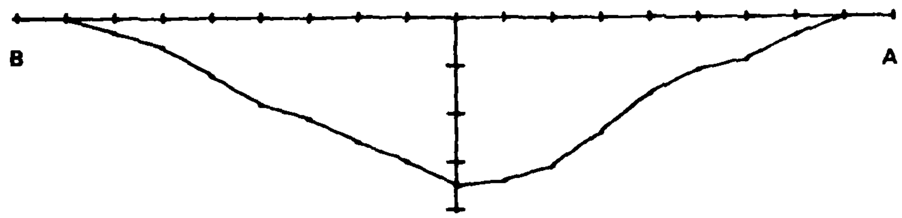


Figure C-57. Crater 52 (TNT).

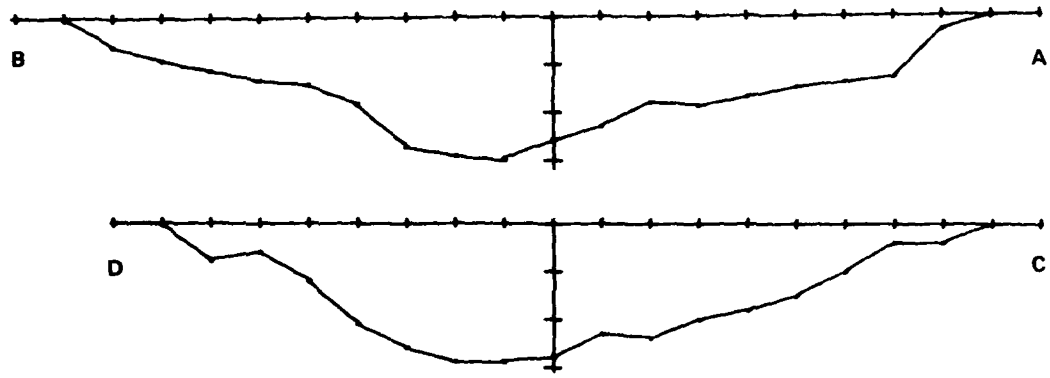


Figure C-58. Crater 53 (105mm).

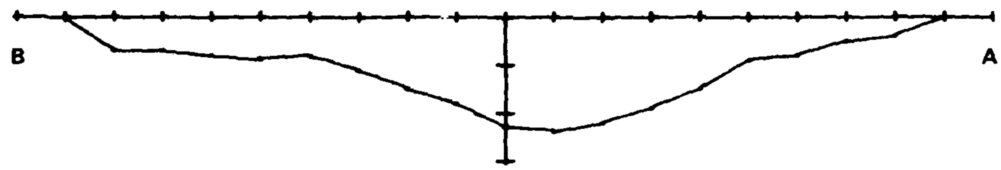


Figure C-59. Crater 54 (105mm).

(Crater 55--See figure C-6.)

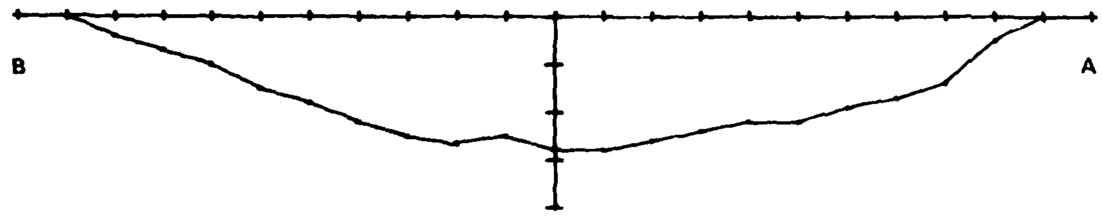


Figure C-60. Crater 56 (155mm).

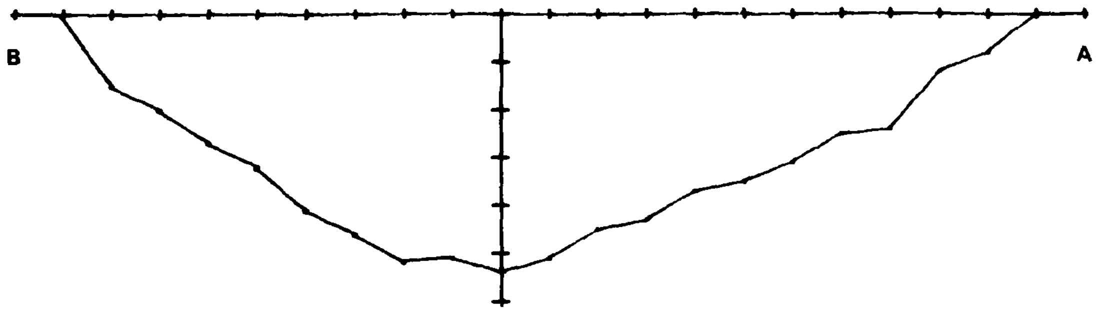


Figure C-61. Crater 57 (TNT).

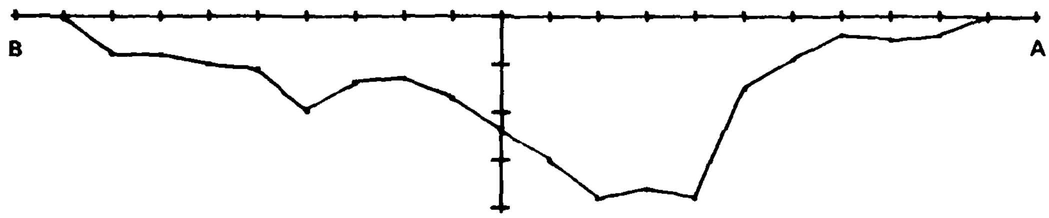


Figure C-62. Crater 58 (TNT).

(Crater 59--See figure C-7.)

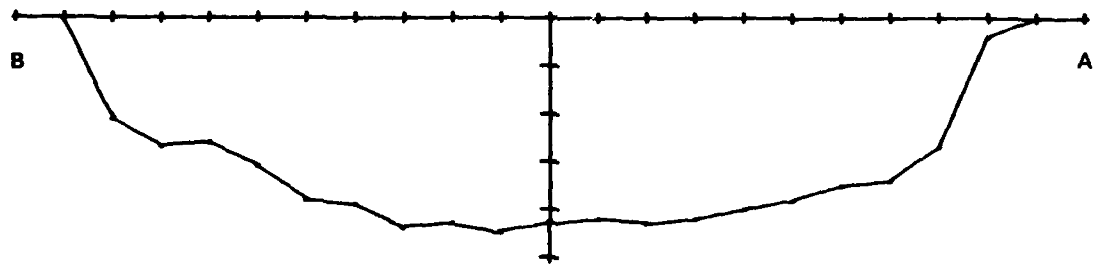


Figure C-63. Crater 60 (TNT).

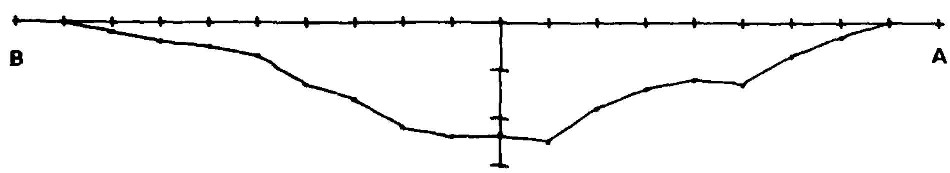


Figure C-64. Crater 61 (105mm).

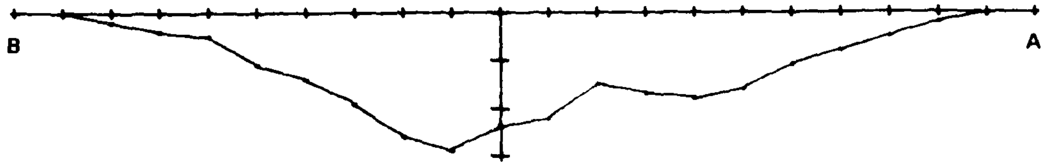


Figure C-65. Crater 62 (105mm).

(Crater 63--See figure C-8).

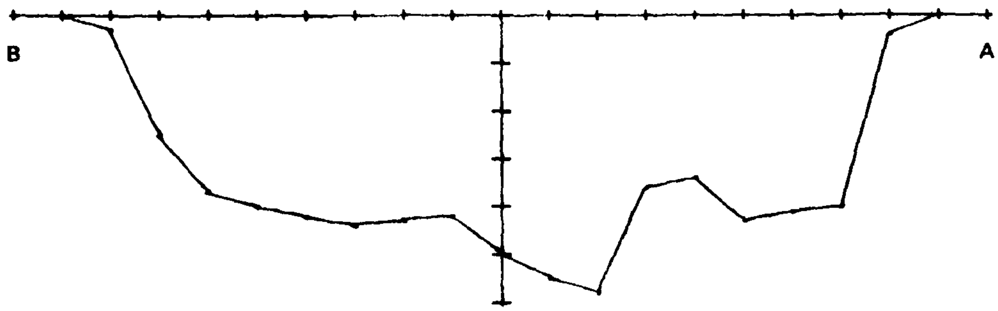


Figure C-66. Crater 64 (155mm).

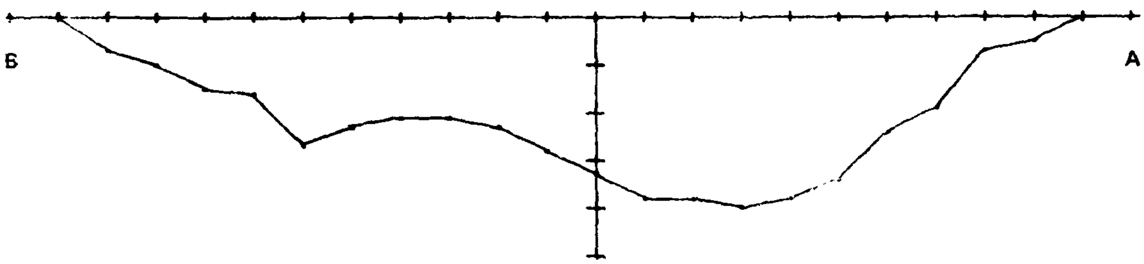


Figure C-67. Crater 65 (155mm).

(Crater 66--See figure C-9.)

One Second.

Twenty Seconds.

Figure C-68. Crater

Ten Seconds.

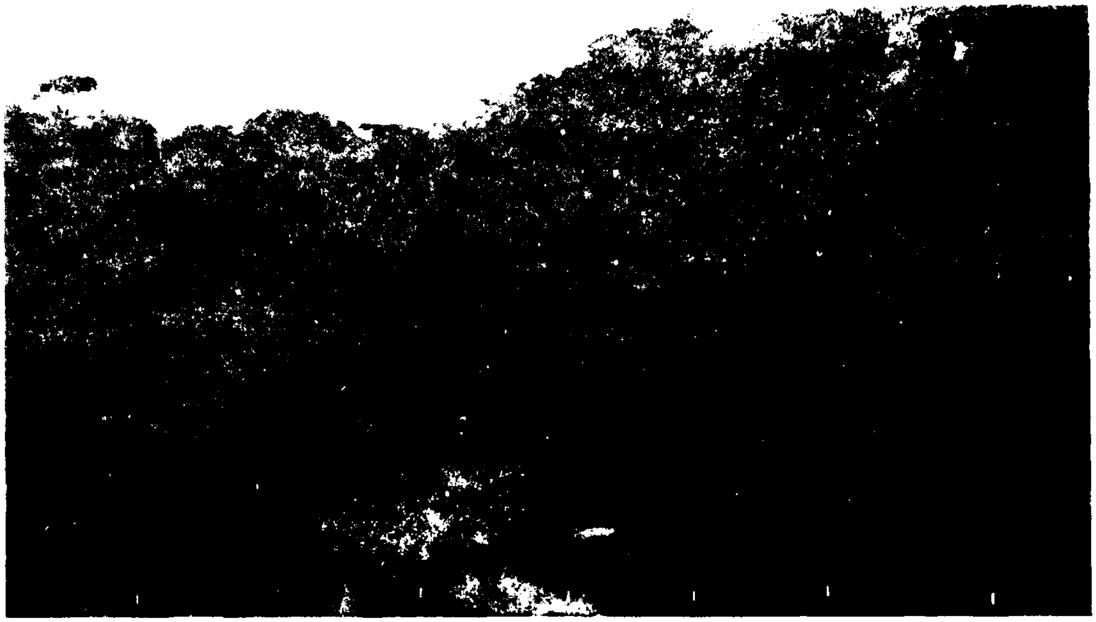
Forty Seconds.

2 at Range 6 (Hill).

One Second.

[illegible] Seconds

Figure C-69. Crater



Ten Seconds.

Forty Seconds.

10 at Range 6 (155mm).

One Second.

Twenty Seconds.

Figure C-70. Crater 22

One Second.

Twenty Seconds.

Figure C-71. Crater 33

Ten Seconds.

Forty Seconds.

at Range 6 (105mm).

One Second.

Twenty Seconds.

Figure C-72. Crater

Ten Seconds.

Forty Seconds.

52 at Range 6 (TNT).

One Second.

Twenty Seconds.

Figure C-73. Crater

Ten Seconds.

Forty Seconds.

58 at Mindi (TNT).

One Second.

Twenty Seconds.

Fiqure C-74. Crater

Ten Seconds.

Forty Seconds.

63 at Mindi (105mm).

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One Second.

Twenty Seconds.

Figure C-75. Crater

Ten Seconds.

Forty Seconds.

64 at Mindi (155mm).

APPENDIX D. REFERENCES

1. Department of the Army Technical Manual 5-530/Department of the Air Force Manual 88-51, Materials Testing, February 1966.

2. TOP 4-2-830, Explosive Cratering Tests, 14 May 1980 (Draft).

3. The Chemical Rubber Company Standard Mathematical Tables, 20th Edition, Editor-in-Chief Samuel M. Selby, PhD., ScD, Cleveland, OH, 1972.

4. SAS Users' Guide, 1979 Edition, SAS Institute, Inc., Raleigh, NC, pp 391 through 392.

APPENDIX E. DISTRIBUTION LIST

ENVIRONMENTAL REALISM—BATTLEFIELD OBSCURATION IN THE TROPICS
TECOM PROJECT NO. 7-CO-RDO-TT1-004

ADDRESSEE	
Commander US Army Missile Command ATTN: DRSMI-MR Redstone Arsenal, AL 35809	2
Commander Harry Diamond Laboratories ATTN: DELHD-I-EB 2800 Powder Mill Road Adelphi, MD 20783	2
Project Manager for Smoke/Obscurants ATTN: DRCPM-SMK Aberdeen Proving Ground, MD 21005	5
Director US Army Materiel Systems Analysis Agency ATTN: DRXSY-R DRXSY-MP Aberdeen Proving Ground, MD 21005	2 2
Commander US Army Test and Evaluation Command ATTN: DRSTE-AD-M Aberdeen Proving Ground, MD 21005	10
Director US Army Waterways Experiment Station ATTN: WES-EN Vicksburg, MS 39180	2
Commander/Director Atmospheric Sciences Laboratory ATTN: DELAS-EO-EN White Sands Missile Range, NM 88002	5
Administrator Defense Technical Information Center ATTN: DDA Cameron Station Alexandria, VA 22314	2

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Director Night Vision and Electro-Optics Laboratories ATTN: DELNV-PA/RA Fort Belvoir, VA 22060	 2
Commander US Army Tropic Test Center ATTN: STETC-MTD-T STETC-MTD-A STETC-MTD-A (TIC) STETC-MTD-O (Tech Ed) STETC-MD-WPB APO Miami 34004	 2 4 15 2 1

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